Instruments

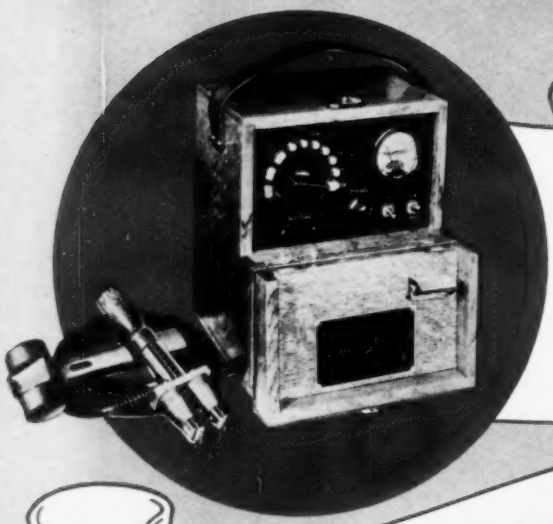
THE MAGAZINE OF

Measurement and Control

Vol. 17
JUNE
1944
No. 6

INCLUDING Aviation Instruments

TAG MOISTURE METERS SERVE MANY A PRODUCTIO FRONT TODAY · · · MORE AFTER VICTORY!



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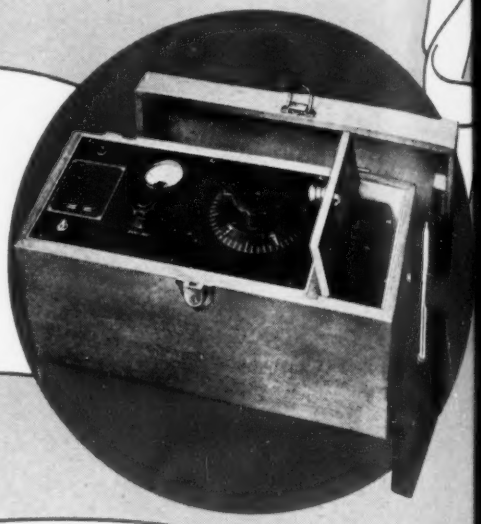
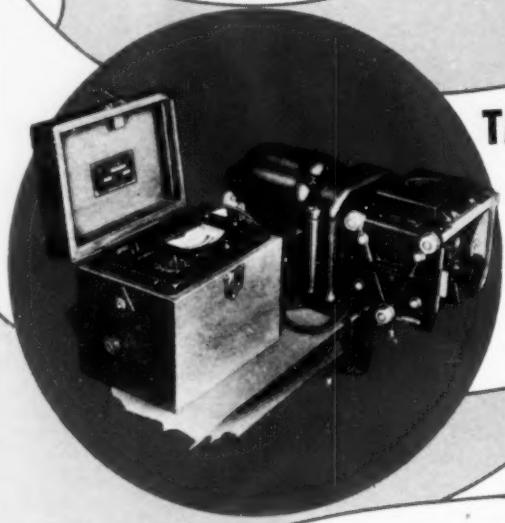
The TAG-Heppenstall Moisture Meter for wood is recognized as the international standard in many lines of industry where wood plays a part. Due to a manufacturing tolerance of ±0.25%, this meter does its job effectively on the plywood, veneers and balsa wood so widely used in the construction of cargo planes, gliders and bombers . . . a practical, metal-conserving factor in the War Program. This instrument has also proven helpful in measuring the moisture content of card and leather board.



FOR POWDER & GRANULAR MATERIALS

TAG Moisture Meter—Dielectric Type. Many products, such as dehydrated foods, flour, plastic moulding material, Army rations and many other similar materials, which cannot be tested by the electrical conductance method can now be measured on the TAG Moisture Meter (Dielectric Type). By means of this instrument, a constant vigilance is maintained over Army rations so that they shall conform exactly to the strict specifications of the Quartermaster Corps. In addition, the Meter is serving by testing the moisture content of dehydrated foodstuffs, thus saving valuable shipping space.



TAG MOISTURE METER FOR GRAIN

This TAG-Heppenstall Moisture Meter was calibrated in collaboration with the United States Department of Agriculture over five crop years for wheat, corn, rye, barley, oats and rice (rough and milled), sorghums, vetch and edible beans to a tolerance of ±0.05°. It helps keep the steady stream of sound foodstuffs flowing to our fighting forces and our allies.

TAG MOISTURE METER FOR TOBACCO

The TAG-Heppenstall Moisture Meter for determining the moisture content of tobacco, constantly guards the products of America's leading tobacco manufacturers which go to the home front and those allocated to the Armed Forces. This Meter has also made possible the discovery and development of many substitutes for products that the present War has made very scarce or impossible to obtain, i.e.—A substitute for manila fibre, a most valuable material for marine rope.

C. J. TAGLIABUE MFG. CO.

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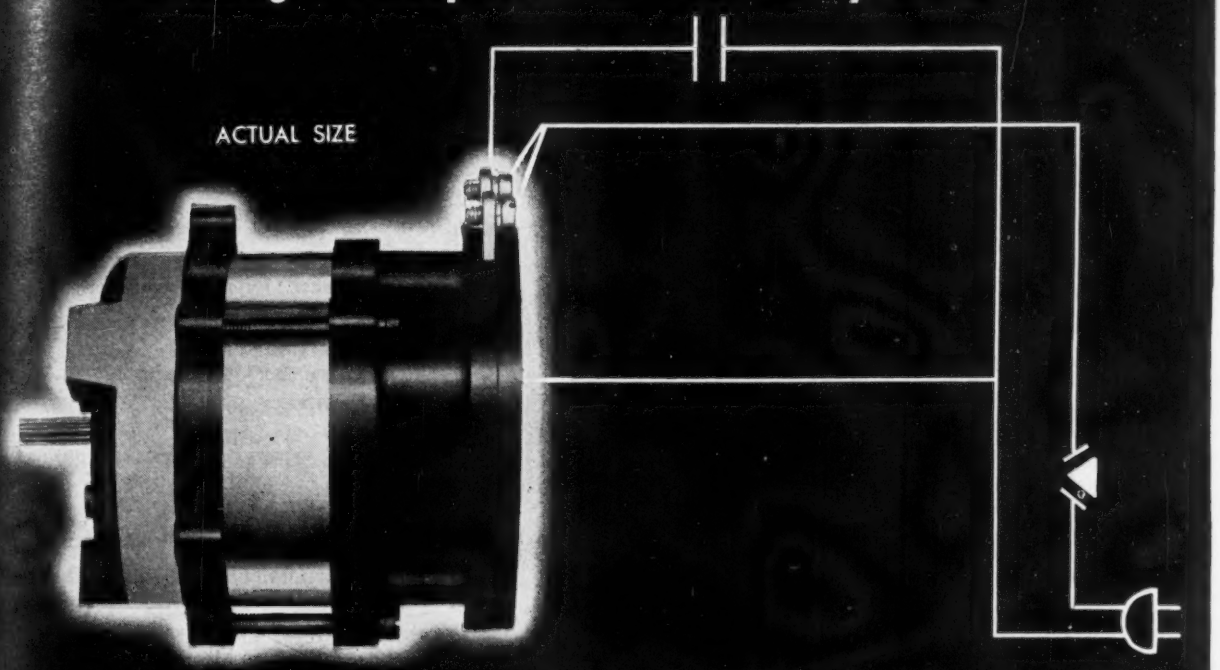
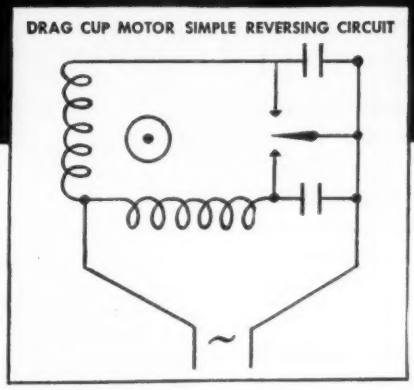
TAG

Design Engineers! ... KOLLSMAN NOW OFFERS

many new types of low-inertia Drag Cup Motors including an adaptable 115 volt 60 cycle unit



DRAG CUP MOTOR SIMPLE REVERSING CIRCUIT



Design Engineers requiring a low-inertia, quick-reversing unit will be interested in the many new types of Kollsman Drag Cup Motors—particularly the new 115 volt 60 cycle units which can be run directly from a regular single-phase outlet with the addition of a capacitor as shown in the main illustration.

The low-inertia, quick reversing characteristics are obtained by a special light aluminum cup, used in place of the usual solid metal rotor. Speed of rotation is varied by controlling voltage input to one or both windings or by varying one phase angle. Direction of rotation may be changed by reversing the leads or phase of either winding.

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In addition to applications as motors, Kollsman Drag Cup Units are sometimes used as induction generators.

OPERATING CHARACTERISTICS—115 VOLT 60 CYCLE DRAG CUP MOTORS

Type	Rotor	Speed	Reversing Time	Stopping Time	Stall Torque
776-05	Aluminum	2930 RPM	.12 sec.	.2 sec.	.50 in/oz.
776-015	Copper	2930 RPM	.20 sec.	.4 sec.	.656 in/oz.

For latest information about Kollsman Drag Cup Motors write to Kollsman Instrument Division of Square D Company, 80-20 45th Avenue, Elmhurst, New York.

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MANOMETERS

Instruments

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(Courtesy Rotameters, Inc.—Cochrane Corp.)

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Instruments THE MAGAZINE OF Measurement and Control

M. F. BEHAR, Editor

Time-saving During the War =Cost-cutting in Post-war =ABUNDANCE

SAVING man-hours—instrumentation's outstanding contribution to the war effort—means during peace-time the reduction of the labor content, and hence of the cost, of goods and services sold to the public. The need of cost-cutting to promote the abundance cycle of mass purchases, mass production and full employment during peace-time, was put in vivid words last month by James Y. Scott, President of the National Machine Tool Builders' Association:

I'm telling you that after this war, cost-cutting is going to be just about the biggest problem in the entire industrial field. You know that wages aren't going down. And you know too that if prices keep going up, American industry won't be able to get the mass markets needed to sustain high-level post-war employment. If American industry can't sustain high-level post-war employment and today's workers are out of work just when the boys come back from the other side looking for jobs, who is going to step in to save the situation? You know the answer: Government will provide the jobs. . . .

Working for Uncle Sam isn't an evil in itself: there will always be national-wealth-creating jobs in the Bureau of Standards, etc. The horrifying possibility is millions of leaf-rakers made inevitable (whichever political party is in power) by financiers crippling American Industry by compelling higher PRICES and disconnecting the spark plug of the abundance cycle: mass consumption.

Good News—New Subscribers Need No Longer Wait

OF all periodicals published in this country, few were harder hit by WPB paper limitation order L-244 than was *Instruments*. Issued in March 1943, this order established 1942 as the base period. It was during that very year, 1942, that the subscription list of *Instruments* had grown from 5,200 to 10,500. Moreover, the RATE of growth was itself increasing early in 1943; the slope of the growth curve indicated that the 20,000 mark would be passed before the end of 1943. There had been a simultaneous growth in the total number of pages per issue of *Instruments*—especially in the number of NON-advertising pages.

Our company's President, Richard Rimbach, thus faced a worse headache than did most other publishers. He will not see these lines until this issue is printed, so I can tell you that he displayed his business genius by refraining from adopting "easy" solutions which would not have been to your advantage in the long run. For your sake, he chose to go for the new low-weight high-grade paper being developed by the paper industry—which is partly owned by giant publishers. "Wise guys" told him he didn't have a chance. To condense a long story into two words: he won. You are seeing and feeling the fruits of his victory as you read and handle this issue, printed on as good a low-weight paper as is being obtained by the most powerful publishers.

Ever since WPB Order L-244 was issued, we had to run a notice to the effect that applicants for new subscriptions would be placed on the waiting list and that belated renewals—even from old subscribers—would go on the waiting list. This is over for awhile. Names of new subscribers are placed without any delay on the mailing list—not on a waiting list. This first announcement is purposely being made on this page in order that those who follow this page—and therefore are believed to be the most serious subscribers—will get all their serious friends to subscribe before the new limit is reached. We are convinced that this will aid the war effort and that an even wider circle of subscribers will also help all the more to bring an economy of abundance to our beloved country after the war is won.

Your Serials

NOTE that the title of this piece is "YOUR Serials." It refers to the serials running in this your magazine. We here in Pittsburgh, and the five Field Representatives who cover the country coast to coast, determine your present needs for information and strive even to anticipate your needs. In many cases our informal but effective "Gallup Poll" (a small-scale but continuous sampling) brings to light some needs of yours which can only be met by presenting you with treatments of new subjects—or with refreshingly new treatments of relatively "old" subjects. Then, instead of hoping and praying that Lady Luck will deposit on our desk a full-length treatment by a competent author, we go a-hunting. For example, sensing the coming of war, we got you Spencer (electrical-instrument servicing) and Bowman (ordnance production gaging). Yes, the result always has been a serial written to specifications we laid down for you—fitting you like a tailored suit and—like such a suit—YOUR serial rather than "a serial in *Instruments*."

These serials are always up-to-date. None is cold-storage. As a rule, each instalment is written in final form a month or so before you see it in print. Therefore it is impossible to comply with a few urgent requests received every month—requests for "a copy of the complete book." It is impossible because the yet-unpublished instalments are not yet in type—sometimes not yet written in final form!

It is intended that reprints of most serials, and perhaps all, will be made available as soon as possible. In 1944, in 1945 and as long as paper limitation orders are in force, a portion of the precious paper tonnage allotted to this company will continue to be used for this useful purpose.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS
SEMI-ANNUAL MEETING
INDUSTRIAL INSTRUMENTS AND REGULATORS DIVISION
Tuesday, June 20—William Penn Hotel, Pittsburgh, Pa.

9:30 a.m.—"Stabilizing a Suction-Relief Valve." ED S. SMITH, Eclipse Pioneer Division, Bendix Aviation Corporation.

"Experimental Studies in Fractionating Column Control." L. H. ALLEN, JR., American Viscose Corporation.

12:30 p.m.—Luncheon for all I.I.R.D. members and their guests.

8:00 p.m.—Symposium on the Adjustment of Floating, Corresponding or Derivative Control Actions. *Contributors:* DON BURNS, The Hays Corp.; "Setting Fan Speed Controllers in Boiler Plants." E. D. HAIGLER, The Foxboro Co.: "Simple Setting Procedures." P. W. KEPPLER, The Foxboro Co.: "Simplifying Adjustments by Use of Cascaded Control." F. M. LECOMPTE, Curtiss-Wright Corp.: "Factors Influencing the Successful Adjustment of Control Equipment." N. B. NICHOLS, Radiation Laboratory, M.I.T.: "Proportional Controller Settings for a Two-capacity Process." M. H. WHITE, Atlantic Refining Company: "Control of Oil Outlet Temperature of Double Pipe Chillers." J. G. ZIEGLER, Taylor Instrument Companies: "Optimum Controller Settings and Tank Volume for Averaging Liquid Level Application."

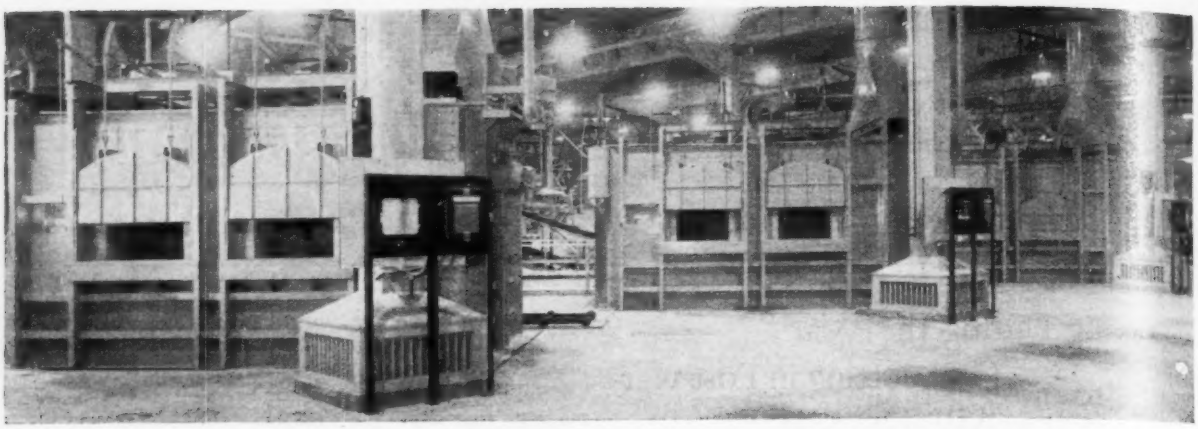


Fig. 1. Aluminum Melters. *(All photographs courtesy Continental Industrial Engineers, Inc.)*

Saving Man-hours and Materials Through Gas and Fuel Control Instrumentation Methods*

By EDWARD A. DIETERLE, Consulting Engineer, Chicago, Illinois

IN the manufacture of gas and in the utilization of manufactured, natural, and liquefied petroleum gases, automatic controls save many man-hours. The controls may be electrical or mechanical, the latter being mainly pressure-operated.

The manufacture of gas involves various processes, depending on the kind of gas made. Coal gas is now mostly manufactured in by-product coke ovens, though there are still a number of stop-end, through, and vertical retort plants in operation. Carburetted water gas is manufactured in many parts of the country, especially in the east and middle west, though natural gas has replaced it in many mid-western communities. Many industries employ producer gas. Steel plants use blast-furnace gas, or mixtures of blast-furnace and coke-oven gases. Some steel plants also purchase natural gas to augment their own supply.

Proper instrumentation is necessary to save fuel and man-hours in connection with all gas manufacturing processes. Time does not allow for a detailed outline in this connection.

For purposes of discussion, controls will be considered as follows:

1. *Temperature Controls:* Better products are obtained through use of these controls and many man-hours are saved. For example, in the open-hearth process used in steel mills, with gas employed as fuel, better products are made in less time when roof temperatures are properly controlled, and cost of maintainance is reduced through longer life of refractory materials. Also, less time and skill are required for more satisfactory operation.

In certain steel mills, soaking pits have been fitted with controls which make them automatic in operation, requiring only observation. This can b done by unskilled labor whereas heret fore they were operated with high skilled specialists. Temperature rat and pressure controls make the heatin process automatic.

2. *Pressure Controls:* Many diffe ent kinds of pressure controls are em ployed in connection with the distribu tion of gases. Individual gas system employing liquefied petroleum gases op erate almost entirely through pressur controls. Industrial furnaces and house hold gas appliances are more or les dependent on such controls as well a on temperature controls. They hel make gas service available to replac slower and more laborious methods o cooking, heating, and cooling.

An instance which demonstrates th value of pressure controls was had re cently by a nationally-known engineer ing organization when inability to se cure a gas pressure regulator for large number of burners resulted in re quiring the services of 24 man-hour per day during the period the regulato was not available. An installation cos of approximately $75.00 enabled them to take this man off this service an place him elsewhere.

Refrigeration plants fitted with con trols employ various gases to effec cooling. It may be of interest to men tion that some of our best lubricating oils are produced through the refrig erating effect of liquefied petroleum gases, such as propane, on certain lu bricating stock.

3. *Flow and Ratio Controls:* These are especially valuable in maintaining the proper relationship of mixed gases in distribution systems, and in main taining proper operating conditions in furnaces, ovens, etc. Premixing of gas and air by such controls allows for di lution of high-Btu. gases to lowe equivalents whereby better products re sult with less labor.

*Presented at the Chicago War Production Conference, March 30, 1944.

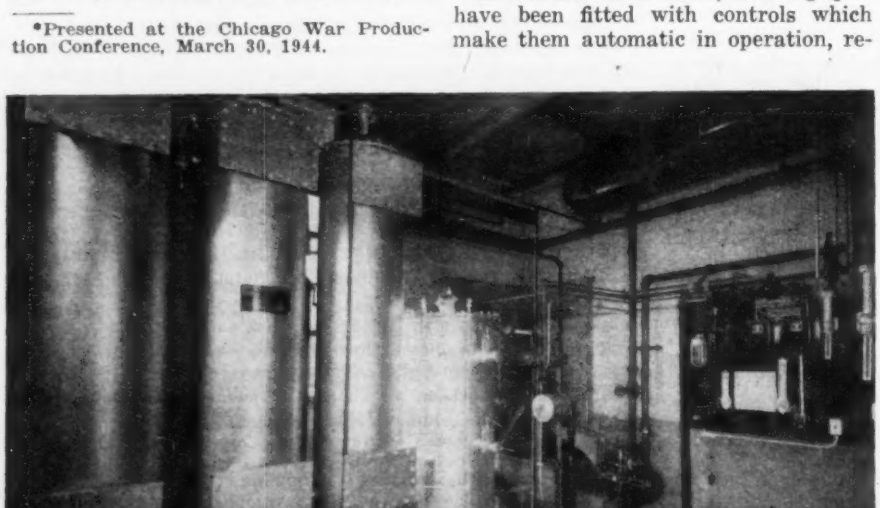


Fig. 2. Inert gas generator for paint, varnish, foods and chemicals.

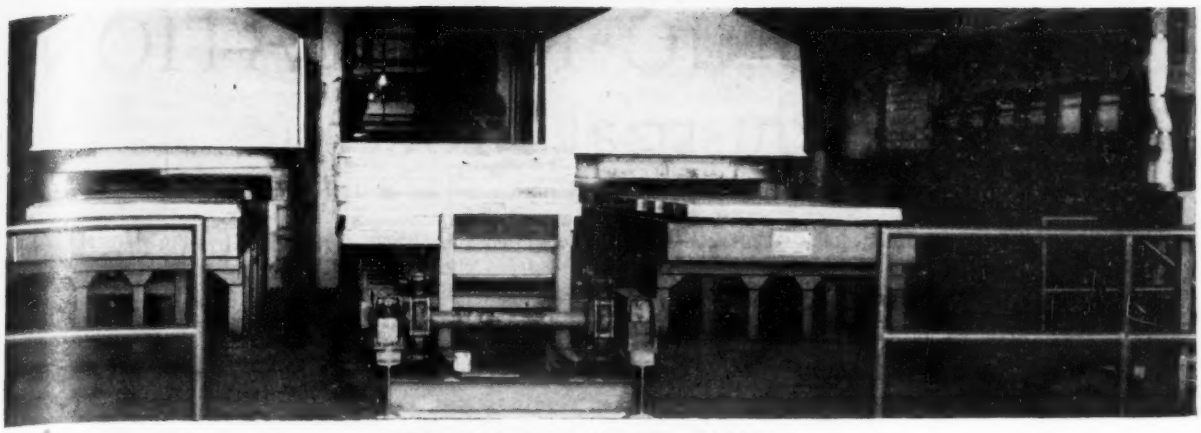


Fig. 3. Cake heaters for copper and brass.

4. *Draft Controls:* These control natural, induced, or forced draft, and may be either electric, hydraulic or pneumatic. They are essential in conserving fuel and time.

5. *Liquid Level Controls:* Such controls maintain proper levels in tanks and boilers, and make for economy in operation.

6. *Humidity Controls:* These are important in producing better products and in preventing spoilage.

7. *Specific Gravity Controls:* These make proper adjustments to take care of heating value changes in conjunction with flow and ratio controls. Some calorimeters function through changes in specific gravity.

8. *Carbon Dioxide Controls:* Such controls tie in with specific gravity and with flow and ratio controls. They are extremely helpful in the saving of fuel, which, in turn, saves man-hours.

9. *Electronic Controls:* Electronic controls, such as the electric eye, save much time and material, and also help prevent explosions in gas-fired furnaces. They also record the density of smoke, and are now being adapted to record temperatures.

INDUSTRIAL APPLICATIONS

Instrumentation necessarily saves man-hours in the following types of industrial gas furnaces and processes:

Metallurgical (See Figs. 1, 3, 4): A number of different processes come under this heading such as smelting, annealing, heat-treating, carburizing, nitriding, sintering, forging, and baking. Carburizing of high-carbon steel under controlled atmospheres in muffle tube furnaces eliminates the necessity for recarburizing. Under such controlled conditions, formation of scale is prevented with low carbon steels. Nonferrous metals may also be thus heated without scale formation.

In nitriding, where natural gas and ammonia are employed in proper proportions and under controlled temperature and pressure, a hardened surface is produced on the steel. This hardened surface wears better, increasing the life of machines. Nitriding has some advantage over carburizing in producing hardened steel surfaces in that lower temperatures can be used (1100 to 1200°F.), and therefore no quenching is required and the material can be cooled slowly.

In foundry practice an important item is core baking, economically done in gas-fired ovens. Accurate control of temperature in all parts of the oven so that it is uniformly heated throughout, is effective in reducing foundry losses. Recirculation of air for core baking, or for any low-temperature operation, makes for uniformity of product. Spotty heats are avoided by large volumes of such recirculated heated air. Underdone cores have water bubbles which come out and produce defective castings, while overdone cores have insufficient strength and are washed away by the molten metal with resultant spoilage.

Chemical: In the chemical industry such important manufacturing steps as amidogenation, calcining, conversion, cooking, and cracking of oils and gases, etc., are performed in gas-controlled furnaces and ovens.

Ceramics: The ceramic industry uses gas in manufacturing brick, tile, pottery, bottles, etc., and temperatures must be closely maintained to prevent spoilage of products. This is done with controls.

Gas-fired radiant tubes are employed in properly controlled furnaces for applying vitreous enamel to steels. In the older method, carborundum muffles are used for this purpose.

Paint and Varnish Industry: In the paint and varnish industry an important item in the cooking of varnish is to protect the material from oxidation. This is done by maintaining the material in a controlled inert atmosphere during the cooking. Inert gas machines supply such gas continuously to the cooking kettles during the processing. These machines are fitted with ratio and flow controls (Fig. 2). Storage tanks are blanketed with inert gas which guards against oxidation and danger of explosions and fires. Carbon dioxide may also be employed for this purpose, but inert gas made from city gas is much more economical.

Foods: Large volumes of gas are used in the food industry for dehydrating, roasting, cooking and canning. Cereal processing plants as well as bakeries require accurate temperatures for constantly good products. Spoilage of materials is prevented and this directly and indirectly saves many man-hours.

In the packing industry, gas is employed in various heating, cooking and smoking processes. The hydrogenation of vegetable and animal oils involves either the electrolytic process, or the

(Concluded on page 370)

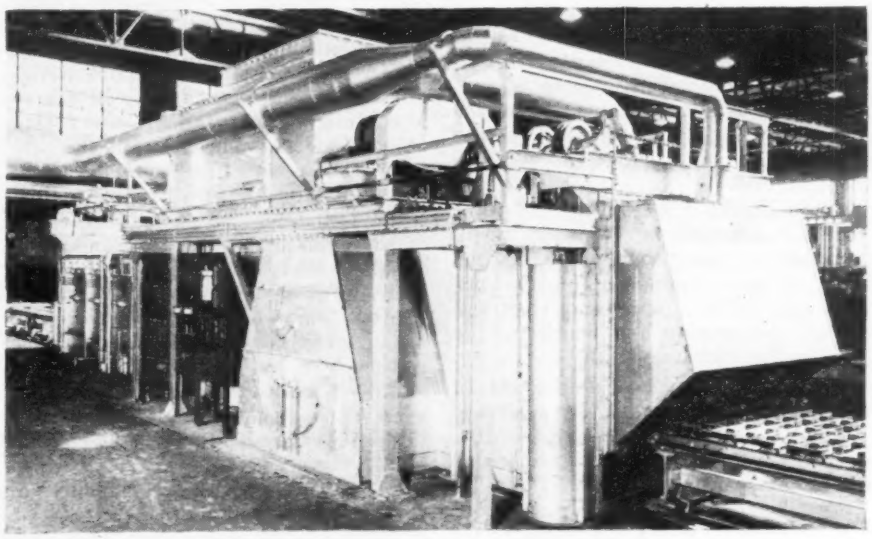


Fig. 4. Recirculating clean annealer for copper and brass.

ELECTRONIC REGULATION of Industrial Processes*

By S. L. BURGWIN, Control Engineering Dep't, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

SO much has been said of the wonders of electronics and so many fantastic pictures have been drawn that the newcomer in this field is likely to be bewildered. As the newcomer becomes more familiar with electronic phenomena of industrial importance, he notes that these phenomena are based upon the basic functions of electronic tubes, which may conveniently be classified under six headings:

(1) Rectification
(2) Amplification
(3) Generation
(4) Control
(5) Transformation of light to electricity
(6) Transformation of electricity to light.

We are all familiar with examples of these basic functions. The electronic automobile battery charger is an example of rectification. Our radio sets would be impossible without amplification just as radio transmission would be difficult without the generation of high frequencies by electronic oscillators. In spot and flash welding, extremely small amounts of power are used to turn on and off electronically the tremendous currents required. Light gives rise to electronic currents in the phototubes used in burglar alarms, door openers, automatic traffic control, etc. In turn light is produced by electronic currents in fluorescent and neon lamps.

Only one or two of the basic functions are utilized in these examples, but in automatic regulation of industrial processes three, four, five and in some cases all six may be put to practical use in a single regulating system. Then, from one point of view, electronics may be considered to attain its highest effectiveness in the field of automatic regulation.

Regulation of a particular variable involves measurement of that variable by comparing it with an arbitrary standard which usually can be preset to a desired value or, let us say, controlled. The regulating system is completed by using deviations from the standard, suitably amplified, to operate a control in such a way as to decrease the deviation.

At this point it may be well to point out a distinction between the terms "regulation" and "control"—a distinction which is coming into more common use in electronic and electrical control engineering and which will be used in this discussion:

REGULATION of a variable is taken to mean *maintenance* of an arbitrary (or arbitrarily varying) value of the variable by feedback or a means inherent in the system.

CONTROL of the variable implies the ability or capacity of *setting* the variable at any particular desired value by *human* operation of a "control means." (Examples of "control means" are hand valves, rheostats, etc.)

ESSENTIAL FEATURES

In taking up the discussion of regulating systems it is desirable to restate and emphasize three fundamental features of regulating systems, the recognition of which is essential in dealing with the problems encountered in applying such systems.

First, a regulating system must always include a standard of comparison —let us say, a "yardstick"—for the variable to be regulated.

Second, deviations from this standard must operate a control means in the system to reduce the deviation, thus establishing a closed system.

Third, a closed regulating system which is capable of storing electrical, mechanical, or magnetic energy in any of its parts and returning this energy to the system, is a potential oscillator and may, unless precautions are taken, result in a wider range of variation of the variable under regulation than would have been experienced without applying the regulating system.

These three statements apply equally to mechanical, magnetic or electronic regulating systems and to their various combinations.

At first thought, the necessity of a yardstick may appear so obvious as to scarcely justify serious discussion. However, in some systems, it is not easy to identify the comparison standard and trouble may arise from the unrecognized use of a standard which deviates from the desired value more than does the variable to be regulated. "Identify the yardstick," is a useful axiom in regulation—as it is in measurement.

Electronic regulators require deviations from the standard to be translated into voltage (either alternating or continuous) somewhere in the system. Therefore, if a voltage can be readily obtained that maintains a sufficiently constant relation to the variable to be regulated, a voltage comparison standard may be used and voltage indications of deviation obtained directly. It often is more convenient, however, to use a comparison standard of the same general type as the regulated variable and to translate deviations into voltages which actuate the electronic regulator. This may be particularly convenient in compensating for changes which affect alike the regulated variable and the comparison standard.

All kinds of comparison standards may be used. Indeed, the success of a regulating system may depend to a great extent upon a wise or clever selection of the comparison standard. Distance between two points is used very often since it usually can be maintained quite accurately by electronic regulators. This, surprisingly enough, is the comparison standard used in the system developed by Westinghouse for regulating temperature in the induction heating of tinning lines. Also, as might be expected, distance between two points is used as the standard in register regulators, slitter regulators, edge control regulators, loop regulators, multicolor press register regulators and many other types. R.p.m. is used as a standard in some papermill drives. Other comparison standards used are: time, light, color, temperature, frequency, current, electrical resistance, etc. The possible types of yardsticks seem to be limited only by the ingenuity exhibited in devising methods of translating deviations from the comparison standard into voltages necessary to actuate the electronic regulator.

High-gain electronic amplifiers requiring extremely small actuating energy make possible the use of a wide variety of "deviation-to-voltage transformers," or "deviation detectors" [i.e., *primary elements*—ED.]. One of the most popular of these is the phototube. Current from the phototube is approximately proportional to light falling upon its cathode.

AN INTERESTING PHOTOTUBE APPLICATION

Many ingenious methods have been devised to make the amount of light striking the cathode proportional to (or at least a function of) the deviations of the regulated variable from the comparison standard. The most recent such method is among the most interesting. It is the application of a phototube in regulating temperature of the flowing operation for continuous tinplate lines. The tin is electrolytically deposited upon steel strip, producing a rough matte surface. The strip then passes through a high-frequency induction heating coil which melts or flows the tin, producing a smooth mirror-like surface having a much increased corrosion resistance. For best results the final temperature must be somewhat above the melting temperature of the tin; but if the temperature is allowed to become too high the surface becomes oxidized and turns a bluish color. Such a surface does not have good corrosion-resistant properties.

The melting temperature of tin is too low for emission of visible radiation and even for the infrared radiation to actuate the phototube, so use is made of the difference between the optical

*Talk before the American Society for Measurement and Control, Pittsburgh, Pa., April 24, 1944.

properties of flowed surfaces and matte surfaces. The change of properties in this application is so sharp as to appear as a distinct line of demarcation between the matte unflowed surface and the mirror-like flowed surface. The temperature of this line of demarcation — called the "flow line" — is the melting point of tin and, therefore, is constant. It follows that the *maximum* temperature attained by the tin as the strip moves through the heating coil is a function of the *position* of this flow line in the heating coil. This makes possible the use of "distance between two points" as a "comparison standard" for temperature regulation. It is accomplished as follows: Two beams of light are focused on the strip on either side of the desired position of the flow line. One phototube is arranged to pick up diffuse light, but not specularly reflected light, from both these spots. Thus, if the temperature drops and the flow line moves out of the desired position so that both spots are on the matte surface, approximately twice the amount of light strikes the phototube, and the current output of the tube is doubled. If, on the other hand, the temperature increases so that both spots are on the mirror surface, the light striking the phototube drops to approximately zero and the current output of the tube also decreases to zero. This variation in current can of course be used to actuate the electronic regulator and control the power input to the induction heating coil to bring the flow line back to the desired position.

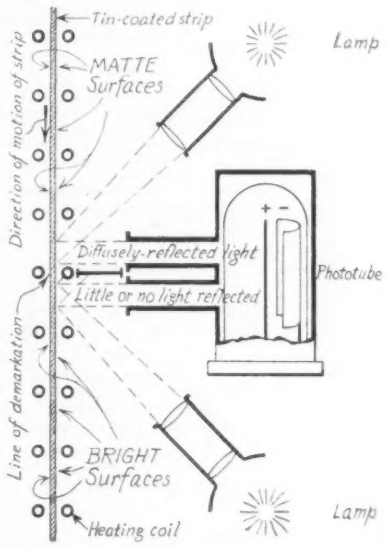
The many other interesting and ingenious applications of phototubes, sliding contacts, microphones, thermocouples, torque meters and even timing mechanisms, as deviation detectors, are a subject for a complete article in themselves and cannot be gone into in this discussion.

AMPLIFICATION

Voltages from the deviation detector are generally too small to be used directly in operating the control means of the system. Amplification becomes necessary. One of the advantages of electronic regulators over mechanical and magnetic regulators is the ease with which almost unbelievably large values of amplification can be obtained. However there are some practical limitations. For instance, input voltage to the first tube of the amplifier must be kept above 10 microvolts and preferably above 50 microvolts since phenomena similiar to the so-called Brownian movement result in the generation of background voltages in vacuum tubes of the order of several microvolts. This background includes all frequencies in practically equal amounts. Input impedance is also limited usually to approximately 1 megohm. Thus input power required to actuate high-gain amplifiers is of the order of 10^{-15} watts.

Power required to operate the control means of the system may amount to several kilowatts or even more. Usually it is not possible to supply this amount of power from vacuum tubes. Therefore the vacuum-tube amplifier is arranged to control the firing of thyratrons through some sort of phase control. Such control will usually require less than one watt output from the vacuum-tube amplifier. Thus the maximum practical power gain in the vacuum-tube amplifier is then of the order of 10^{15} or 150 decibels. This corresponds to a voltage gain of approximately one or two millions.

Usually, such high gain is unnecessary and gains of a few hundred or thousands are all that are required.



Purely schematic diagram drawn specially for *Instruments* to illustrate description by S.L.Burgwin of new method of TIN-FLOWING TEMPERATURE CONTROL (no diagram having been released by W.E.&M.G.). MFB

This is fortunate if the input voltage is direct or of low-frequency nature as high-gain d-c. amplifiers are still something to be dreamed of. However, d.c. can be amplified by use of a carrier frequency when the additional complexity is justified.

Our regulating system now consists of a comparison standard; a detector, and a vacuum-tube amplifier. The next part of the system to be considered is the control of the thyratrons. Thyratrons differ from vacuum tubes in that the only function of the control grid is to start conduction. Conduction continues uncontrolled by the grid until the applied voltage drops to a value less than the arc voltage of the tube, then conduction ceases. If the applied voltage is alternating, the average value of the output voltage can be controlled by varying the phase position in each cycle at which conduction starts. If even more power is required, ignitrons can be controlled in the same manner by the thyratrons.

Circuits have been devised in which the average power output per cycle from the thyratrons becomes a continuous function of the output voltage of the amplifiers. In other circuits the voltage output of the amplifiers acts to bias the thyratrons so that an increase of amplifier voltage fires one thyratrons or bank of thyratrons full-phase to give rectified voltage of, let us say, positive polarity at the load while a decrease of amplifier voltage below normal fires another thyratron or set of thyratrons to produce rectified voltage of negative polarity at the load. Such a circuit can be simply adjusted for no dead zone (by which is meant the region of no control) or for dead zones of almost any desired width. In another type of so-called trigger circuit the polarity of the output is determined by the order of a series of signals.

Choice of thyratron control circuits is dictated by the type of regulating system required and the method of controlling the regulated variable. The power controlled by the thyratrons may be used to supply the field of a generator or d-c. motor or even the armature of a small d-c. motor. In some applications it supplies power to the d-c. winding of a saturable-core reactor and in others it merely actuates relays or contactors.

STABILITY

The regulating system is now complete except for discussion of the third and perhaps most important point, that of stability of the system. In this discussion the oscillating or astatic type of regulator and its limitations will be discussed first and then the static type, with some discussion of the various methods of eliminating oscillation.

It was stated earlier that a regulating system in which energy can be stored and returned to the system is a potential oscillator. This classification includes practically all but the simplest of regulating systems. Devising means of discouraging or stopping the natural oscillation of such systems is one of the more fascinating problems of control engineering. Since the solution of this problem is difficult for many systems, there is a strong tendency to allow the system to oscillate where the regulating requirements are not too stringent. The resulting class of oscillating or astatic regulators comprise a large percentage of all existing regulators.

Some rough generalizations on the behaviors and requirements of oscillating regulators are helpful in determining where regulators of this type are most useful:—

(1) The period of oscillation when not subjected to transients is roughly proportional to the sum of the delays in the systems.

(2) Amplitude of oscillation when not subject to transients is roughly proportional to the product of the period of oscillation and the speed of correction.

(3) Thus in a system having a given delay the speed of correction is limited by the allowable amplitude of oscillation.

(4) When the system is subjected to transients the maximum amplitude has an inverse relation to the speed of correction.

(5) Therefore when speed of correction is increased the amplitude of tran-

sient swings decreases but the amplitude of oscillation increases.

These generalizations indicate that the oscillating type of regulator may be used where severe transients are not encountered, or where wide transient swings are not objectionable. However, one objection to the use of the oscillating type of regulator, which should not be overlooked, is the continuous duty of moving parts—although this criticism is not so pertinent when applied to purely electronic regulators.

If duty on moving parts is too heavy or if a slight added improvement in regulation is desired, a dead zone of sufficient width to just stop oscillation can generally be introduced in the control system. Such an addition, beside relieving duty on moving parts, results in improved regulations by decreasing the amplitude of deviation of the regulated variable from the comparison standard by values amounting in some instances to as much as 50%.

If still further improved regulation is necessary, and it is not possible to reduce the delays in the system, a more complex type of regulator of the static type must be used. The simplest of these is one in which the correcting force is made roughly proportional to the deviation of the regulated variable from the comparison standard and an anti-hunt device is used which in effect damps out oscillation. Use of so-called anti-hunt has the advantage of ease of adjustment but the disadvantage of slowing up response in correcting for transients. A good example is a voltage regulator such as shown in Fig. 1. Here the generator voltage to be regulated is compared to a battery voltage. Voltage differences are amplified and applied to the phasing control of the thyratrons supplying rectified current to the exciter field. Anti-hunt action is obtained by subtracting from the generator deviation voltages a voltage roughly proportional to the change in exciter armature voltage. In spite of the reduced speed of correction due to this anti-hunt feature, regulation will in general be better than could be accomplished by the oscillating type or by the dead-zone type.

Still further improved regulation can be had by resorting to an "anticipatory" regulating system. Such a system is shown in Fig. 2. In this system a voltage proportional to the *rate of change* of the *generator* voltage, and a voltage proportional to the *rate of change* of the *exciter* voltage, are added to the generator deviation voltage. If these two voltages after amplification exactly compensate for the inductive voltages of the exciter and generator fields, practically perfect regulation should result—provided, of course, that the maximum rate of correction is high enough to match any transient that may be encountered.

It might be added here that the same results could have been obtained in this case by using the proper amounts of first and second time derivatives of the generator voltage added to the deviation voltage to actuate the amplifier as shown in Fig. 3, provided of course that the generator and exciter saturation curves were sufficiently linear. In this respect this system is a special case, as generally in complex systems such a simple solution is not possible.

Regulating systems of the type discussed in the last two paragraphs result in the most satisfactory regulation when properly designed and adjusted. However, there are some disadvantages in that design of such systems usually requires a good knowledge of the constants of the systems which oftentimes are hard to obtain. Furthermore, unless a rather thorough analysis is made, proper adjustment is difficult.

In the simpler regulating systems one regulating "cue" or at the most two were all that were required. In the more complex systems such as these just discussed the number of cues may in the worst case be equal to one plus the number of locations of stored energy in the system. Furthermore, each cue may be taken from a different variable in the system. Extreme flexibility of design and wide range of application are demanded to fully realize the possibilities of these more complex systems. Generally, these demands can only be satisfied fully by electronic regulators.

The discussion of regulating systems will not be complete without some more or less general comments on the design of a regulator.

First, the delays in the regulator as constituted by the deviation detector, amplifier and power control should be kept small relative to the delays in what may be termed the "utility system" which usually cannot be changed.

Second, required speed of correction depends qualitatively upon the power available and the inertia of the utility system. For instance a high-inertia system with low available power will not need a high speed of correction.

Third, where a high degree of stability and close regulation is required, extreme range and flexibility in regulator design are required to make full use of the anticipatory type of regulating system.

In many systems consideration of these three points rule out all but electronic regulators. In other systems where the delays in the system are greater, the necessary speed of correction less, and a wider latitude in regu-

(Concluded on page 369)

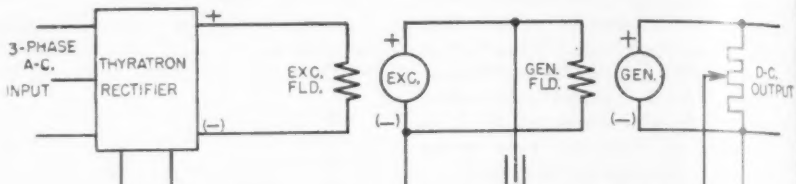


FIG. 1. VOLTAGE REGULATOR WITH ANTI-HUNT

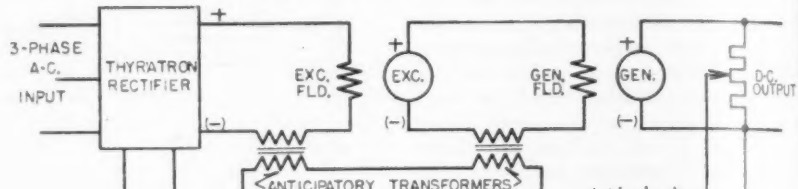


FIG. 2 VOLTAGE REGULATOR WITH ANTICIPATION

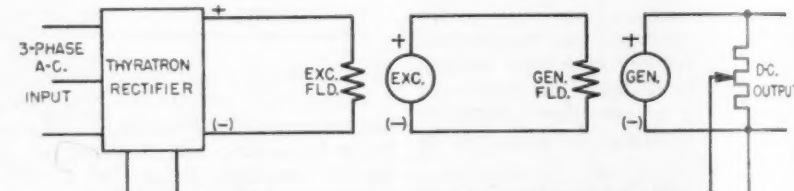


FIG. 3. VOLTAGE REGULATOR WITH 1ST AND 2ND DERIVATIVES

The Field of Force in which We Always Live

A Refresher for Instrument Men

By S. R. WILLIAMS, Professor of Physics, Amherst College, Amherst, Mass.

We can't get away from it! We are prisoners held steadfast in its tentacles! Without it we couldn't walk or do many other things to our advantage. What is this enslaving force which holds such sway over our lives?

It seems to be a well-authenticated story that during an epidemic in Cambridge, England, Newton, having just received his B.A. degree at the University of Cambridge, returned to his old home in Woolsthorpe and while there noted that the apple as it fell from the tree always fell toward the earth. Meditating upon this phenomenon, Newton came to the idea that the earth attracted bodies to it as a magnet attracted iron filings to one of its poles, but he also pointed out that this force which attracts or holds us to the earth's surface is not a magnetic force in its character. From the fall of the apple to the moon in its orbit was a flight of Newton's imagination which showed that the almost circular orbit of the moon was a motion under the balanced forces of the attraction of the earth and the tendency for a body moving in a curved path (see Dec. '43 article) to go off in a straight path. Both of these forces could be calculated and which Newton finally did and found them to agree.

These calculations led Newton to the formulation of his law of universal gravitation:—that every particle in the universe attracts every other particle in the universe with a force which is proportional to the product of the masses of those two particles and inversely as the square of the distance between their centers of mass. Stated in a formula and adding the constant of proportionality this law has the form

$$F_g = G\frac{M_1 M_2}{d^2}$$

where G is the gravitational or Newtonian constant. It is not a pure number but depends upon the choice of units for the other quantities. Thus, in the metric system, G is the force in dynes between two 1-gram masses when their centers of mass are one centimeter apart. Its value is:

$$G = 6.670 \times 10^{-8}\ \text{dyne-cm}^2\text{g}^{-2}.$$

Take the case of two fair-sized men whose masses are 70 kilograms apiece and let us suppose they stand with their centers of mass 50 centimeters apart. They are attracted toward each other with a force,

$$F_g = \frac{70000 \times 70000}{50^2} \times 6.670 \times 10^{-8}\ \text{dynes} = 0.1307\ \text{dyne}.$$

When we realize that a small weight of one gram is attracted toward the earth with a force of 980 dynes we can understand the small force just calculated. If on the other hand, we replace the value of M_1 and M_2 by the masses of the earth and the moon, for instance, and the distance d as the distance between the centers of mass of the earth and the moon, then we see what enormous forces are continuously in play between these relatively small celestial bodies.

Can these forces of attraction between smaller bodies actually be measured?

I. Cavendish Experiment

The simplest demonstration we have of the universality of the force of gravity is to be found in the now classical experiment of Henry Cavendish, first director of the physics laboratory at the University of Cambridge, England, in 1798.

Two equal spheres of platinum, m_1 and m_2 (masses of about one gram each), are mounted as shown in Fig. 1 on the ends of a light bar (about 2.5 cm. long). At the center of the bar is a mirror and the whole system is suspended by a fine quartz fiber, q, from some rigid, steady support. The upper end of the fiber is attached to a fixture which can be rotated about a vertical axis coincident with the fiber. This system is then suspended between two lead balls, M_1 and M_2, whose masses are about 3 kilograms apiece. When these two lead spheres are in the position M_1 and M_2 the deflection of the system will be that of the continuous line for the bar connecting m_1 and m_2. When M'_1 and M'_2 are the positions of the two lead spheres, then the system

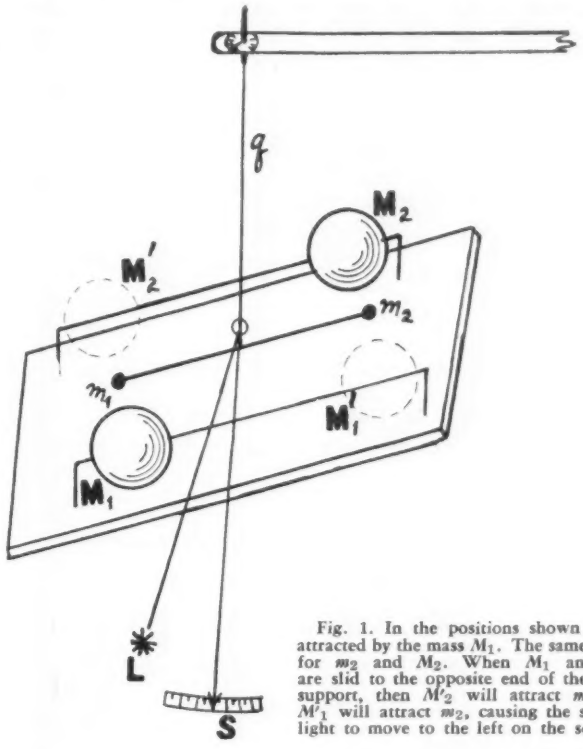


Fig. 1. In the positions shown m_1 is attracted by the mass M_1. The same holds for m_2 and M_2. When M_1 and M_2 are slid to the opposite end of their rod support, then M'_2 will attract m_1 and M'_1 will attract m_2, causing the spot of light to move to the left on the scale S.

carrying the two platinum spheres will turn so that m_1 and m_2 are nearer M'_1 and M'_2. This motion can be indicated by the light spot from the source L moving over the scale S. In the first case m_1 and M_1 will attract each other by a force

$$F_1 = G\frac{m_1 M_1}{d^2}$$

similarly for m_2 and M_2

$$F_2 = G\frac{m_2 M_2}{d^2}$$

If the torque constant of the fiber is known, then F_1 and F_2 can be determined and hence G can be evaluated. This is an experiment which has been repeated many times since Cavendish's day and once the value of G is determined we can determine the average density of the earth.

At the surface of the earth a mass m is attracted to the earth by a force,

$$F_g = G\frac{mM}{R}$$

where R is the radius of the earth. Furthermore, since, as we saw in the Nov. 1943 issue, a force is defined by the equation,

$$F = ma,$$

the force of gravity acting on a mass m can be expressed by a similar equation wherein the acceleration is g with which bodies fall and so,

$$F_g = G\frac{mM}{R^2} = mg.$$

or,
$$M = gR^2/G$$

This experiment by Cavendish is often referred to as "weighing the earth" because from the determination of G we can find the mass M of the earth

$$\frac{M}{V} = d = \frac{M}{\frac{4}{3}\pi R^3}$$

$$d = \frac{3g}{4\pi GR}$$

In using g it must be remembered that its value varies over the surface of the earth and the value used must be that where the Cavendish experiment is carried out. On the surface of the earth g is greater at the poles than at the equator. There are two principal reasons for this: At the poles the pull of the earth is increased because the earth is flattened by rotation and the body is nearer the center of the earth. Also, at the equator, the body is farther away from the center and there is the greater tendency for a mass to fly off at the equator than at the pole, because there the centrifugal force is greatest.

II. Richarz and Krigar-Menzel Experiment

Another experiment for determining the value of G was performed by Richarz and Krigar-Menzel in 1898. Fig. 2 will indicate the scheme employed for finding G. A balance

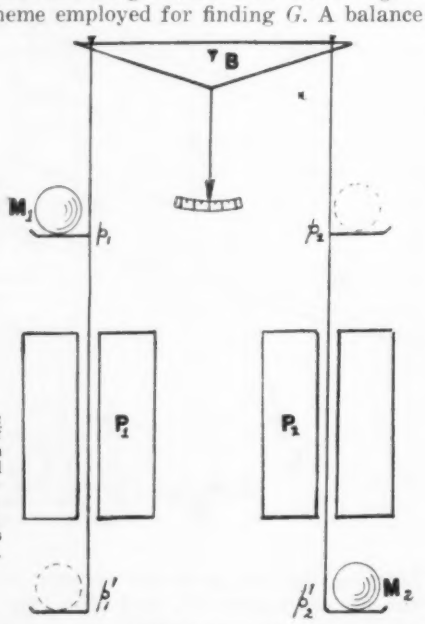


Fig. 2. The mass M_2 being nearer the center of mass of the Earth than M_1, has a greater pull exerted upon it. The parallelopipeds of lead P_1 and P_2 also pull on M_1 and M_2. These differences in forces may be measured.

beam, B, 23 cm. long, was mounted at some distance above the floor F. From each end of the beam were suspended two pans, p_1 and p'_1 and p_2 and p'_2 respectively. The pans p_1 and p_2 were near the beam and the pans p'_1 and p'_2 were located over 2 meters below the others as shown. The procedure was as follows: Equal platinized copper kilogram masses M_1M_2 were used and, to begin with, these were placed one in the upper left hand pan and the other in the lower right. The position of rest of the pointer was then found by vibrations. Next the mass in the upper left was put in the lower pan under it where it gained weight because it was nearer the center of the earth, while the mass in the lower right was put in the upper right where it lost weight because it was farther from the center of the earth. The result after corrections was that the mass in the left hand pans appeared heavier by 1.2453 mg., half of this being due to the change in position of a single kilogram mass.

A further test could be added to this experiment, viz., that between the two pans a lead paralleopiped of separate blocks was built up, 2 meters high and 2.1 meters square in the horizontal plane. The balancing process was again repeated but the attraction of the lead which was reversed when the masses were interchanged between the upper and lower pans. The attraction of the lead mass more than made up the loss in the force of gravity, and the left hand mass now appeared lighter when going through the some operation by 0.1211 mg. The attraction of the lead alone made a difference of 1.3664 mg. This is four times the attraction of the lead on a single kilogram. Knowing the pull of a block of lead of known form and density on a kilogram at a known distance, and knowing also the pull of the earth on the same kilogram (10^6 mg.) the density of the earth could be determined.

Their final result was:—

$G = 6.685 \times 10^{-8}$ dyne-cm^{2}g^{-2}

Av. density $= 5.505$ g/cm^3

III. Airy's Experiment

Sir G. B. Airy carried out another experiment in 18[illegible] whereby he could determine the average density of the earth and so its total mass. It consisted in comparing the values of g as found by the pendulum when swinging the same pendulum, first at the top and then again at the

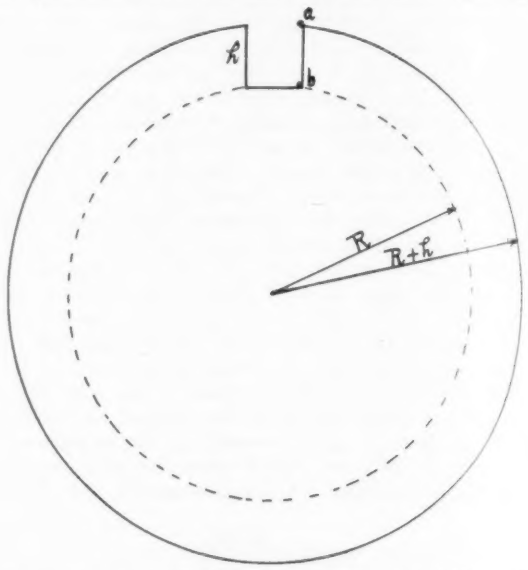


Fig. 3. a-b represents the side wall of a pit in a mine. a and b are the two stations where the pendulum was swung.

bottom of a deep mine. Actually, the difference in height between the two stations where the pendulum was swung was 1250 feet. When a pendulum is set to swinging the value g may be found from the equation for the period

$$T = 2\pi\sqrt{(l/g)}$$

where l is the length of the pendulum and g is the acceleration due to gravity which is to be determined.

If a small mass m is placed at the surface of the earth it will be attracted by a force

$$F_g = mg = G\frac{mM}{R^2}$$

where M is the mass of the earth, R its radius and G the gravitational constant.

If we draw on an exaggerated scale the pit in the mine as shown in Fig. 3, then at the bottom of the pit,

$$g_b = \frac{4\pi GR^3\Delta}{3R^2}$$

where R is the radius of the earth reaching to the bottom of the mine pit, and Δ the average density of earth, or

$$g_b = \frac{4\pi GR\Delta}{3}$$

At the top of the mine m will be attracted not only by the sphere calculated for g_b, but by a shell of the earth whose thickness is h or equal to the distance between the two stations, viz., 1250 feet. The area of this shell is $4\pi(R+h)^2$ and the mass of the same acts upon m as though it were concentrated at a distance $(R + h)$. Let δ be the density of the shell which can be experimentally determined. Then mass of shell,

$$M = 4\pi(R+h)^2 \times h \times \delta$$

At the top of the shaft,

$$g_a = \frac{4\pi R^3\Delta G}{3(R+h)^2} + \frac{4\pi(R+h)^2 h\delta G}{(R+h)^2}$$

$$= \frac{4\pi R^3 \Delta G}{3(R+h)^2} + 4\pi h \delta G \quad \cdots$$

$$= (\tfrac{4}{3}\pi R \Delta)\left(1 - \frac{2h}{R} + \frac{3h}{R\Delta}\right) \text{ (approx.)}$$

Hence,
$$\frac{g_a}{g_b} = 1 - \frac{2h}{R} + \frac{3h\delta}{R\Delta}$$

and
$$\frac{\Delta}{\delta} = \frac{3h/R}{[-1 + (2h/R) + (g_a/g_b)]}$$

From this relation, taking into account the ellipticity and rotation of the earth, Δ was found to be $\Delta = 6.565$ g./cm.^{3} Hence the mass of the earth is $\frac{4}{3}\pi (Rh)^3 \times 6.565$. In other words, the earth has been weighed.

IV. Bouguer's Experiment

A fourth method for showing the universal attraction which matter has for matter is illustrated by Bouguer's plumbline experiment on the attraction of Mt. Chimborazo, a mountain about 20,000 feet high whose mass above the station level could be found with some degree of accuracy. If a plumbline were hung up on a level plane its axis would be exactly parallel to the axis of a telescope set to

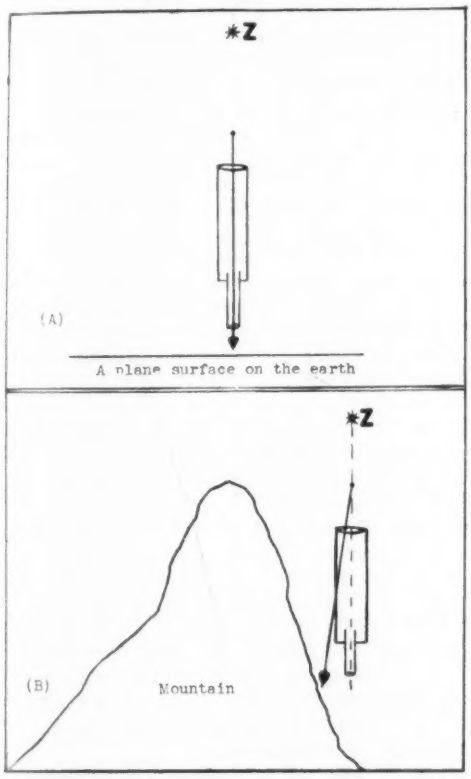


Fig. 4. (A) On a plane surface of the earth the axis of a plumb-line and that of a telescope seem to intersect at the zenith. (B) Along side of a mountain the plumb-line is pulled away from the vertical and the axis of the plumb-line does not intersect with that of the telescope at the zenith.

observe a point directly at the zenith or straight overhead. If this same plumbline is brought near a mountain the two will attract each other and the plumbline is pulled toward the mountain. Fig. 4 shows how the plumbline will be deflected away from the vertical. This is to say that the ratio

$$\frac{\text{Mountain pull}}{\text{Earth pull}} = \tan \alpha$$

where α is the angle of displacement of the zenith.

Taking the density of the mountain as 2.5 g./cm.^{3} another experimenter by this same method found a value of 4.5 g./cm.^{3} as the average density of the earth.

A survey of the various methods and experiments which have been carried out to measure the mass of the earth shows that the evaluation of G has been sought for by a great many experimenters and by a large number of methods.

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ELECTRIC GAGING METHODS
for Strain, Movement, Pressure and Vibration

By HOWARD C. ROBERTS, University of Illinois

IV. GAGING METHODS BASED ON VARIATION OF INDUCTANCE

§1. Pick-up Devices: Variable-inductance Type.

Gaging methods operating on magnetic principles comprise the second of the three principal classes of electric gaging methods. Most magnetic gages operate through change in inductance — either self-inductance or mutual inductance—of the gaging element. Some utilize the change in reluctance of a part of a magnetic circuit, and a few utilize other magnetic phenomena. There is no clear line of demarcation between different types.

The pick-ups used in magnetic gaging systems have been made in many forms. In contrast to the situation described in the last chapter (where only a few pick-ups of simple construction were used, but many electric circuits) there is as much variety in the magnetic pick-ups used as in the basic types of the associated electric circuits.

Magnetic pick-ups are sometimes of quite complex construction; some have almost the entire gaging circuit contained within the body of the pick-up. The simpler pick-ups are the more flexible in application, but less well compensated than the more elaborate ones.

Magnetic gaging element must always be supplied with energy, in some manner. It is convenient to classify those which are energized by electromotive forces as variable-inductance gages, and those which are energized by magnetomotive forces as variable-reluctance gages.

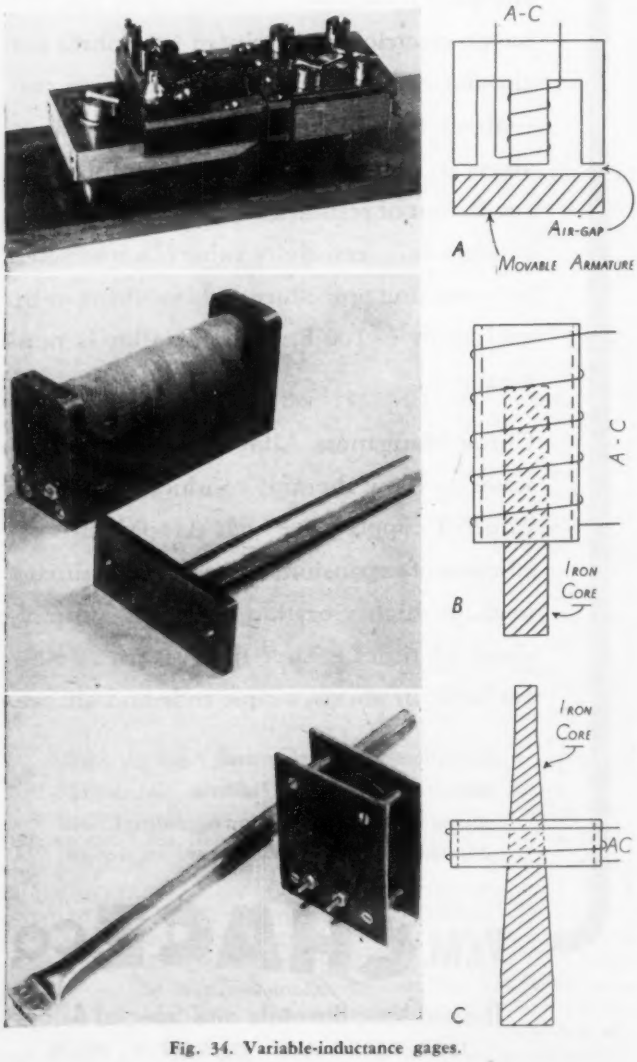


Fig. 34. Variable-inductance gages.

Magnetic gaging circuits are usually low-impedance circuits. They are therefore capable of carrying relatively heavy currents, and many of them do not require electronic amplification.

The most elementary type of magnetic gaging element is the *variable-inductance* element.

Inductance is one of the three fundamental parameters existing in an electric circuit. Self-inductance—the inductance of a single inductor—may be defined roughly as that property of the circuit which impedes the flow of alternating current.* It differs from resistance in this respect, since resistance offers the same impedance to alternating as to direct current. Some ohmic resistance, however, is always present in any inductor. The unit of inductance is the henry.

The self-inductance of a coil depends upon the number of turns of wire it contains, its shape and dimensions, and the magnetic permeability of the core. No simple mathematical relation has been set up for computing the inductance of coils in general. However, the inductance of a coil increases as the square of the number of turns, as the square of the diameter, and approximately linearly as the permeance of the magnetic flux path. It decreases as the flux path is lengthened, or made less permeable. Since the number of turns and the shape of the coil are not conveniently varied, most variable-inductance gaging elements are so constructed that the permeance of the magnetic circuit is varied by the movement being measured. Such a change in permeance is easily provided by altering the length of an air gap in the magnetic circuit, or the position of some permeable member lying partly within the flux path.

In Fig. 34 are shown three variable-inductance pick-ups and with them the symbols by which they are indicated in the diagrams. One (A) is designed for measuring strains; it is simply a small iron-core coil with an air-gap, and it is so constructed and so mounted that the effect of the strain is to change the length of this air-gap. Most of the reluctance of the magnetic circuit appears in this air-gap. If the length of this air-gap is 0.010″—a typical value—and the base-length of the gage is 2″, a strain of 0.001 inches per inch will change the length of the air-gap by 20 percent, and the impedance of the gaging element by nearly the same amount. (Reluctance in a magnetic circuit is analogous to resistance in an electric circuit. Permeance is the reciprocal of reluctance.)

Pick-up B in Fig. 34 is designed for measuring movements as great as two inches. It consists of a coil of about 300 turns of wire wound on a tube of insulating material with a movable core of magnetic material. As the magnetic core enters into the solenoid coil, the inductance of the coil increases in a manner roughly proportional to the amount of metal within the coil.

Pick-up C in Fig. 34 is designed for measuring movements of several inches, or several feet. Its coil is a short multi-layer coil of many turns; its core is a tapered bundle of soft iron wires, enclosed in a tube. The core threads the coil at all times; its effect upon the inductance of the coil depends upon the area of its cross-section within the coil. The core may be as long as desired; its cross-section must taper (for this coil) from about one-third of one square inch to about one-tenth of one square inch. This is not an efficient type of gaging element, but has the advantage that it can be applied to the measurement of distances of many feet, and that (by proper proportioning of the core cross-section) the calibration curve may be

*For definitions and formulae see Section 5 (page 000) in which the theory is treated in some detail.

given almost any shape desired. The inside diameter of the coil in these pick-ups is somewhat larger than the core; some radial displacement of the core can be accommodated without the introduction of appreciable inaccuracy.

Fig. 35, A, B, and C, illustrates the manner in which the impedance of each of the three pick-ups varies with the movement experienced. The impedance is the effective

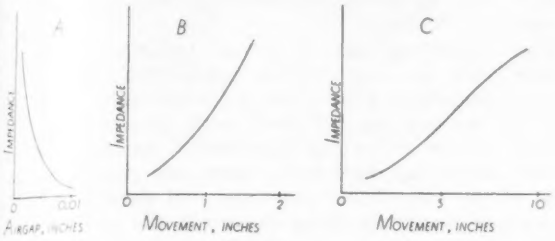


FIG. 35

resistance of the unit, and includes both ohmic resistance and the inductive reactance. The inductance of pick-up A is much higher than that of either B or C because of the more permeable flux path; both B and C have only a small proportion of iron in the flux path.

Coils of this type, whose inductance is varied by the presence of magnetically-permeable material, have been applied to the indication and measurement of magnitudes of many types. From the indication of position of an elevator in its shaft, and its acceleration, to the measurement of viscosity by the velocity of fall of a steel ball in a tube filled with liquid—from the measurement of density of tiny samples of liquid to the remote indication and control of the level of the water in a city reservoir—all these have been accomplished by this simple variable-inductance gaging device.

These gages are representative of most of the variable-inductance pick-ups. It is possible (although not convenient in most instances) to construct an inductor whose proportions can be varied to alter its inductance; for example, a helical spring has been so used. It also is possible to change (effectively, at least) the number of turns in an inductor; the moving-coil variometer does this. But the most efficient and the most widely-used gages have been the variable-air-gap iron-cored units. Instead of iron, high-permeability magnetic alloys have been used.

§2. Pick-ups: Push-pull Types

From these simple variable-inductance devices, it is an easy and a logical step to the *inductance-ratio* pick-up. The inductance-ratio element is one in which the movement being measured causes a simultaneous change in two similar inductors, increasing the inductance of one and at the same time decreasing the inductance of the other. It is therefore a push-pull device.

The gages illustrated in Fig. 34 are easily converted to inductance-ratio types. In Fig. 36 are shown two gages which are the push-pull forms of gages A and B of Fig. 34.

Gage A in Fig. 36 consists of three parts—two laminated iron cores connected together mechanically, and a single laminated iron armature between them. Each of the cores carries a coil; the inductance of these coils is (as in the previous description) varied as the movement of the armature increases one air-gap and decreases the other. Construction of the gage is more difficult than for the simple variable-inductance type. In this particular gage the armature is attached to one metallic member, the two iron cores with their coils to another, and these two assemblies are linked together with flexible metallic strips to maintain alignment. In this gage the coils are replaceable, so that coils of suitable characteristics for the proposed use can easily be introduced.

Gage B is mechanically quite similar to its prototype. Instead of a single solenoid winding, however, it has a center-tapped winding. Its iron core is always entirely within the coil; the ratio of the inductance of the two halves of the coil is controlled by the position of this movable core.

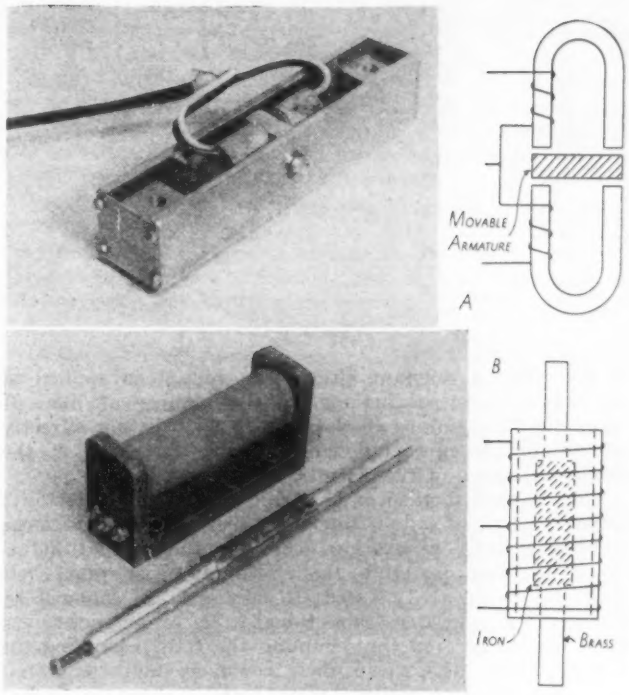


Fig. 36. Inductance-ratio gages.

These push-pull gages are somewhat more difficult to construct, and slightly more expensive to install (they require three-conductor connecting leads) but they have decided advantages over the simpler types. In addition to doubled sensitivity, the linearity of response is improved over that of the variable-inductance gaging elements. Compensation for temperature, lead resistance and other factors is far easier. They do not exert an appreciable force upon the specimen (or moving element) other than that due to their weight. This is important in many applications. Inductance-type gages operating through change of air-gap can easily be so constructed as to involve no pivoted or sliding joints; therefore mechanical hysteresis from these sources cannot occur. The change in air-gap experienced by the gage in Fig. 34A is a result of elastic deformation of the specimen entirely. Such a gage exerts force upon the specimen from its weight and from the magnetic effect of the exciting current; neither of these forces is appreciably changed by the value of applied strain. This characteristic makes the gage suitable for long-time applications, such as creep measurement; in such applications there is no question of gage slippage or any other factor which might result from any restraining action of the gage.

If the push-pull inductance-ratio type of gaging element is used, the forces due to the magnetic effect of the exciting current balance each other, and there is little or no force from this cause transmitted to the specimen (or to a measuring-element pointer). If an application requires that these forces be made entirely negligible, the gaging element can be made small in size and light in weight, the exciting current kept low, and an electronic amplifier employed to raise the output to a level at which rugged instruments can be applied to indicate the phenomenon.

On the other hand, if a suitable design of element be used, and the exciting current made quite high, the magnetic forces can be made to actuate an indicating device. Such a system, termed an induction balance, is one form of inductance-ratio element, and has had extensive industrial application.

§3. Pick-ups: Mutual-inductance Types

Another form of inductance-ratio gaging element is one in which the effective impedance of a coil is altered by changing the *mutual inductance* between it and another circuit.

Mutual inductance is a property of two associated coils or circuits, and determines the voltage (or current) induced

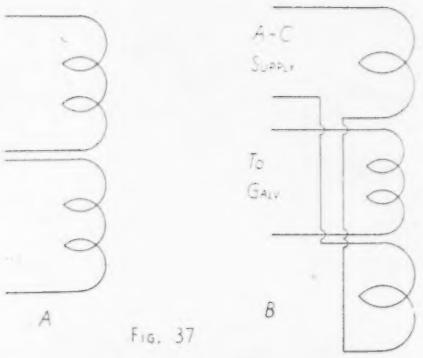


Fig. 37

in one when a constant alternating voltage is applied to the other. It is proportional to the number of lines of magnetic flux linking both coils, but it is not directly affected by the current flowing in either circuit or by the ohmic resistance of the circuits.[63]

The simplest method of changing the mutual inductance between a pair of coils is to change their relative positions; increasing their separation decreases the mutual inductance, as does changing their orientation so that their magnetic fields are opposed. It may also be changed by altering the length, cross-sectional area, or magnetic permeability of an iron core coupling the coils. Changing the length of an air gap in their common magnetic circuit is a most effective method of changing the mutual inductance of two associated coils.

An elementary mutual-inductance gaging system consists simply of two coupled coils, one with an alternating potential applied, the other connected to some device capable of measuring the induced alternating current. The movement to be measured is caused to change the distance between the two coils, or their orientation. Such a device is quite inefficient, because the criterion of measurement is the small change in a relatively large current. If air-core

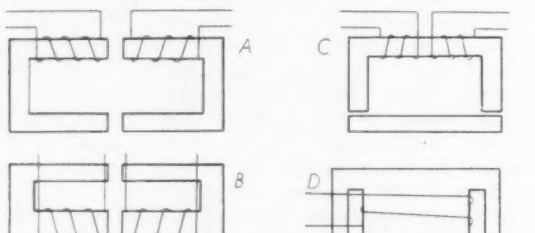


Fig. 38

coils are used, it is necessary to use high-frequency excitation or to have a heavy exciting current flowing.[64]

A more desirable form employs two exciting coils connected in "series-opposition" and connected together mechanically, with a third coil connected to the indicating instrument. This third coil experiences the movement to be measured. The series-opposition connection provides a region in which the fields of the two exciting coils counteract each other, and in this region no current is induced in the moving coil. But the slightest movement of the coil places it in a field where some current is induced within it and indicated on the attached instrument. By this means the output of the gage is made proportional to the magnitude being measured, instead of being a small differential quantity and therefore somewhat difficult to measure accurately.[65]

In Fig. 37 are shown the symbols representing the two devices just described. The author has used gages of the second type. One such gage has a base-length of less than one inch; its moving element weighs less than one-fifth ounce. Because of the balanced construction, no magnetic forces act on the specimen. The gage is excited by radio frequency and is not affected by even intense 60-cycle fields if properly installed, with some shielding. The indicating system comprises a radio-frequency amplifier and an output-meter indicating instrument. This pick-up was intended for creep measurement and has proved moderately satisfactory. Its principal shortcomings are mechanical construction difficulties.

The variable-air-gap iron-core transformer has been widely used; its most effective application is in the detection of deviations from some reference value. The circuit and the air-gap are adjusted until the deflection of the pointer of the indicating instrument reaches some established value—say half-scale; then any change in dimension of the piece being inspected will change the air-gap and cause a corresponding change in the pointer position. Such instruments are often set up as limit gages. Fig. 39 includes a few of the forms taken by such variable air-gap transformers. The form of Fig. 38D is especially well suited to the checking of thickness of iron or steel plate or of thickness of an insulating layer on plate of constant

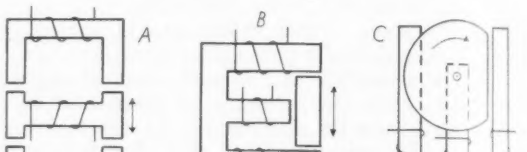


Fig. 39

thickness. All gages operating on this principle have this disadvantage mentioned above—it is necessary to measure a small change in a relatively large current.

In order to avoid this difficulty, and to make it possible to provide an output current (or voltage) proportional to the displacement of the moving iron armature or other element, other mutual-inductance-type gages have been developed. In most of these there is, effectively, an entire gaging circuit built within the pick-up itself. All are based upon the "series-opposition" type of connection previously described.

The prototype of this group of gages takes the form of Fig. 39A; in this gage the central movable armature carries a coil which is connected to the indicating instrument. Both end-pieces (fixed in position and to each other) carry coils, and these coils must be similar and similarly excited; they are so connected that their fields in the movable armature oppose. At the central position of the armature, therefore, no current is induced in the armature coil; if it approaches either coil, however, the field of that coil predominates, and an alternating current is induced. The induced current is proportional to the relative strength of the two fields, or to the displacement of the armature; it has the same phase as that of the near fixed coil. If the direction of displacement is to be indicated, the indicating device must be, in effect, a phase-meter as well as a milliammeter.

Another form of this gage, Fig. 39B, is electrically similar to that of Fig. 39A but mechanically different. In this form the two exciting coils are wound on the two outer legs of a three-legged core, the pick-up coil on the central one. The moving armature carries no coil; the construction and installation are thus simplified. The armature is caused to move in the direction of the arrow; the electrical behavior of the device is then similar to that just described. Displacement of this armature at right angles causes a change in both magnetic circuits, and while this does not entirely balance out in the output, it is reduced. This type of pick-up is easily applied to the measurement of torsional displacement. Fig. 40 shows such a pick-up.

The same general style of magnetic circuit is capable of use for continuous indication of phase position of a rotating shaft; Fig. 39C indicates the method followed. All

(63) A. E. Kennelley. Electrical Vibration Instruments. The Macmillan Co., New York, 1923. 450 pages.

(64) A. Guillet. Mesure Électrique des Petites Longeurs. *Comptes Rendus des Séances de l'Académie des Sciences*, Vol. 146, 1908, pages 465-467.

(65) A. Linford. The Electrical Transmission of Flow and Level Records. *Beama Journal*, Vol. 47, 1940, pages 97-101.

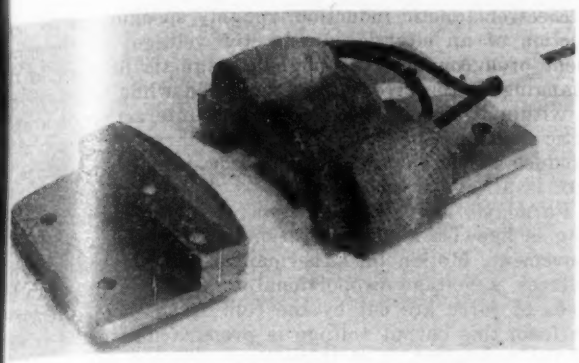


Fig. 40. Mutual-inductance type torsional strain gage.

f the coils, the two exciting as well as the single pick-up oil, are wound on the three legs of an iron core. The rmature, however, instead of being movable in transla- ion, is rotatable, and is so shaped that the ratio of the agnetic reluctance of the two magnetic circuits varies s the angular position of this armature changes; the out- ut of the device can be made to resemble, in magnitude nd in phase, the phase position of the rotating armature. areful design of pole-pieces and the air-gaps is necessary.

For indication or recording of rotation—and particularly or position repeating—phase-responsive devices are widely sed. Typical of these are the Selsyn and Autosyn motors, he induction balance, and several similar instruments. ome of these devices are actuated by phase-shift solely, ome by phase-shift in combination with other effects.[66,67] ince in position-repeating systems the circuit is usually ore characteristic than the pick-up device, the discussion f these systems will be placed in the section on electric ircuits.

There are other types of gaging elements based upon he principle of change of mutual inductance; some of hem are drawn in Fig. 41. Design A is no more than two ariable-air-gap transformers connected mechanically in ush-pull; electrically they are connected so that their out- uts oppose each other. When the moving armature is at enter, there is no output. In B the same is true, but in this esign all coils are wound upon a single four-legged core, nd a small moving armature is spaced between them. ovement of this armature toward either of the pole-pieces arrying no coils has little or no effect, since effectively hese two blind pole-pieces are in parallel; movement of the rmature toward either of the wound pole-pieces produces current output.

Pick-up C in Fig. 41 is quite novel in several respects. here are two separate straight soft-iron cores, each carry- ng two coils. Between the two cores, whose ends must be achined smooth, is placed a specimen of material whose hickness is to be measured; this material may be either agnetic or non-magnetic, insulating or conducting. It may e air, if movement rather than thickness is to be measured. A different calibration is required for each different mate- ial. The interaction of the fields of the two units depends pon the magnetic reluctance of the material separating hem, just as in other gaging elements. But the variation hich is utilizable for measurement is due more to the eakage inductance of the two units than to their mutual nductance directly. The instrument is classed as a mutual- nductance type, however, since the leakage inductance and he mutual inductance are interrelated. This will be dis- ussed in Section 5 on theory.

The pick-up drawn as Fig. 41D is a rather elaborate de- ign; it is based upon mutual inductance principles, but it mploys them in a manner different from those already escribed. The moving armature carries a coil, and rotates bout an axis at its center. The flux from the exciting coils lows (as indicated by the small arrows) through the com- posite center leg and returns through the outer legs. Its path through the center leg, however, and particularly through the moving armature, depends upon the position of the armature. When the armature is in its central position, the path of the flux is at right angles to the length of the armature; there is no flux threading the armature coil, and no induced voltage. If the armature is rotated as shown, some of the flux follows along the length of the armature, since the magnetic reluctance of that path is relatively low, and thus a voltage is induced in the armature coil. If the armature is moved in the other direction, the path of the magnetic flux through the armature is reversed, as is the phase of the induced voltage.

In the previously-described gaging elements, the variation in inductance has in general been produced by the introduction of magnetic material into the field of the inductor, or by changing the effective amount of such magnetic material. An analogous effect can be produced by introducing material which is conducting but not magnetic. If, for example, the soft-iron armature used with the movement gage of Fig. 34B is replaced by a copper bar, eddy currents will be induced in the copper, and the effect of these eddy currents will be to produce a phase shift in the exciting current flowing in the winding. This phase shift causes a change in the admittance of the unit, and this change can be used as a criterion of the presence or position of the copper bar. (The iron armature is constructed of a bundle of soft-iron wires enclosed in a split soft-iron tube in order to minimize eddy currents, which would reduce both sensitivity and efficiency.)

For measurement of movements of several inches, solenoids wound upon straight iron cores and surrounded by movable copper sleeves are often used.[68] The same electrical

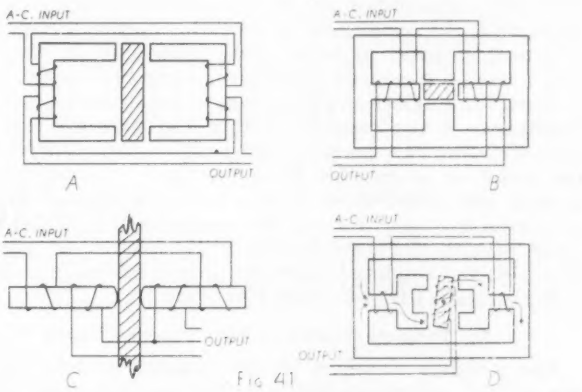


Fig. 41

principle is employed in an electrically-recording manometer, the copper sleeves being replaced by a mercury cup, with the level of the mercury in the cup, and therefore the admittance of the coil, controlled by the differential-pressure or liquid level being measured. This principle is used in many practical industrial instruments. A modification of this device, especially suitable for remote recording, utilizes two coils upon the same core, with the mutual inductance between them being changed by the presence and position of a copper sleeve or by the depth of the mercury in a non-conducting cup. The voltage induced in the secondary coil is measured.

The writer has made effective use of a type of mutual-inductance pick-up depending upon a type of coil structure which, so far as he knows, has not been previously described. A long solenoid is wound with a variable pitch: the turns of wire being close together at one end of the coil and their separation gradually increasing to a maximum at the other end. A short close-wound coil, placed within this, is moved axially by the movement being measured. The flux density along the variably-wound coil varies from one end to the other, and the current induced in the moving coil therefore depends upon its position in the stationary coil. The short moving coil has been replaced in

(66) B. H. Smith and R. T. Pierce. Automatic Transmission of Power Readings. *Journal of the American Institute of Electrical Engineers*, Vol. 43, 1924, pages 101-105.

(67) Anon. Remote Repeating and Summating. *Instrument World*, Vol. 4, 1931, pages 147-148.

(68) Anon. Der heutige Stand der Fernmesstechnik. *Elektrotechnik und Maschinenbau*, Aug. 17, 1930, pages 773-774.

some gages by a copper slug, which has induced within it eddy currents, thereby changing the admittance of the primary coil. The device usually requires excitation with high-frequency current; it is a special-purpose construction, desirable for only a few applications.

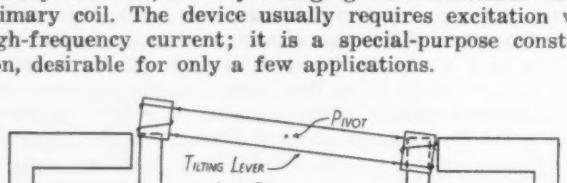


FIG. 41E

Another mutual-inductance device, depending entirely upon coupling between iron-core coils, is sketched in Fig. 41E.[69] It is widely used for remote indication of position. It consists of two iron-core transformers, each with one of its coils movable through a slot in the core. These two movable coils are connected electrically in series, and mechanically are connected to a linkage which moves one coil out of the flux path of one transformer core and at the same time moves the other into the other magnetic flux path. There is no coupling between the transformer cores except through the connecting link circuit, and the amount of this coupling is controlled by the position of the two connected coils. The output voltage of the unit therefore is the criterion of position for the movable element.

Many of the mutual-inductance gaging elements just described may be used in more than one manner. If one of the windings is energized with direct current, the gage can often be made to act as a variable-reluctance type gage. Or if a sheet or plate of conducting material is placed within the air-gap of a mutual-inductance gage, there will usually be eddy-currents induced which will affect the admittance or the reflected impedance of the gage coils. By employing a suitable electric circuit, the thickness of sheet material, either magnetic or non-magnetic, may be measured without touching the material.

Since the production of eddy currents depends upon the resistance of the material within the magnetic field, if discontinuities are present which affect the resistivity of the metal, it is possible to detect their presence by the amount and distribution of such currents. Special circuits have been developed for non-destructive testing of this type. They will be discussed briefly in the section on circuits. The pick-ups employed often are small helical or solenoid coils; excitation is with high frequency.[70]

§4. Pick-up Devices: Reluctance Types

The pick-ups classified in this chapter as belonging to the variable-reluctance type are distinguished primarily by the manner in which the exciting electric energy enters the system. In these devices the energy is introduced as a magnetomotive force, which may be derived from either a permanent magnet or an electromagnet assembly.

Most of these devices are generators; that is, mechanical energy must be introduced into the measuring element where, usually through electromagnetic induction, it is converted into electric energy. In general such devices are reversible; so that electric energy could be introduced and be converted into mechanical energy. In these respects the reluctance-type elements differ basically from the variable-inductance elements: a variable-inductance gage may be likened to a valve which upon the incidence of a movement permits an amount of fluid proportional to that movement to flow into a channel where it can be conveniently measured. Some power is required to operate the valve, but it is an infinitesimal amount. And the device is not reversible.

From these statements the conclusion may be drawn that reluctance-type gages are best suited to dynamic applications, in which there is ordinarily a considerable amount of power which may be spared to actuate the gaging device, and in which the need for static indications seldom occurs.

Electromagnetic induction, roughly speaking, is the production of an electric current (or voltage) by the movement of a conductor through a magnetic field, or by the changing of the strength of that field while the conductor is within it. In either case it is the interaction of a magnetic field and an electric conductor in such manner as to produce a current: a change of position or a change of flux is always involved.

Faraday's own demonstration of electromagnetic induction is likewise a demonstration of a method of detecting movement. Motion of a permanent magnet within a coil induces a voltage proportional to the rate at which the lines of force are cut by the coil. If the field strength is uniform this output voltage is proportional to the velocity of the movement. It is immaterial whether the magnet or the coil is the fixed element: the actual requirement is that there be relative motion.

The most widely-used device of this sort is the moving coil or "dynamic" loudspeaker. There it is employed as a motor, but by suitable mechanical modifications it can equally well serve as a generator. When so applied, its voltage output is proportional to the *velocity* of the moving coil (assuming the exciting field to be constant). The general design of such a device is indicated in Fig. 42A. Either a permanent magnet or a d-c.-excited electromagnet may be used. Such a unit requires some mechanical power

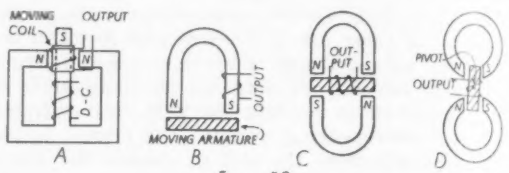


FIG. 42

for its actuation; that power is proportional to the power required by the indicating or recording instrument plus that required to overcome friction. This condition is defined by Lenz's Law.

It is equally practicable, and mechanically often preferable, to maintain the coil in a fixed position with reference to the magnetic field, but to cause the movement to be measured to vary the strength of that field. In Fig. 42B is drawn a device of this type. Here the coil is attached to the magnet, and the magnetic circuit is completed by a movable armature of magnetic material. Changes in the position of this armature change the reluctance of the magnetic circuit, while the magnetomotive force remains constant; thus the magnetic flux varies, and a current is induced in the coil. This current is proportional to the rate at which the magnetic flux varies; therefore it is proportional to the rate at which the armature is displaced. The gage is sensitive to velocity.

In such a pick-up, the coil can be placed around the armature quite as well as around the magnet. If this is done, it becomes possible to install two magnetic structures facing each other in the pick-up, and to place the armature, surrounded by the coil, between them. Twice the flux change is then obtained by the same movement of the armature, and therefore twice the output. The action of the pick-up is like that of a push-pull device under these circumstances, and better linearity of response is obtained. Such an arrangement is shown in Fig. 42C. For mechanical convenience the armature is often fixed to the case of the device, and the magnet assembly is made the moving element. The magnetic forces on the armature are balanced when it is in its rest position.

For some applications the pick-up is modified as in Fig. 42D. The armature in this pick-up rotates about a pivot placed at its center, and the magnets are placed at opposite ends of the armature instead of reenforcing each other. As the armature changes its position, the direction and amount of flux passing through it are changed. The induced voltage is proportional to velocity (the angular velocity, approximately) of the armature.

These pick-ups, in which the variation of reluctance of a magnetic circuit is applied as a transducing principle, have been made in many different mechanical forms. In their

(69) A. Linford. The Electrical Transmission of Flow and Level Records. *Beama Journal*, Vol. 49, 1942, pages 367-372.

(70) A. J. Mee. Application of Physics in Chemical Industry. *Journal of Scientific Instruments* (London), Vol. 20, 1943, pages 137-141.

anner of operation all are essentially alike. Some other forms are shown in Fig. 43. An unusually interesting and useful form of this type of measuring element, sketched in Fig. 43 A, is used to detect eccentricity or unbalance in rotating shafts, particularly in small high-speed motors. This pick-up consists of a permanent-magnet assembly carrying a coil, and a rotating circular armature which may be attached to the shaft *or itself be part of the shaft;* it is so placed that movement of the armature produces an output from the coil. By changing the angular position of the stationary magnet assembly, the position for maximum output may be ascertained; this locates the angular position of the unbalanced mass, or the eccentricity, of the rotating shaft.

Another special type of magnetic measuring device appears as Fig. 43B. This pick-up is based upon the phenomenon of eddy-current generation. A conducting plate is

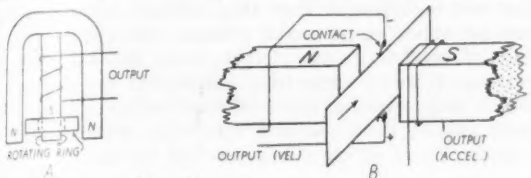


FIG. 43

caused to move (either to rotate or to be moved in translation) in a magnetic field whose direction is at right angles to the plate. Under these conditions, eddy currents are induced in the plate. It is possible to pick off, by means of movable contacts or brushes, a potential which is proportional to the velocity of the motion. Or, by placing coils close to the plate, the eddy currents within the plate will induce other currents within these pick-up coils; the voltage output of the coils will be proportional to the acceleration of the plate. In the drawing, a flat plate or strip is shown passing between the poles of a permanent magnet, one of which carries a coil. It could as well have been a rotating disk. In the first case the device can measure velocity or acceleration along the line of motion of the plate; in the second it can measure angular velocity or acceleration. In any eddy-current device, most of the mechanical energy absorbed by the device is dissipated as heat in the moving plate. Much more mechanical power is required to actuate eddy-current devices than moving-coil pick-ups.

Obviously, any generating device can be put to use to indicate the phenomenon operating it; some tachometers, for example, utilize a-c. generators, while others use d-c. generators. Any type of acyclic generator could be used just as is the eddy-current principle described in the preceding paragraph. These methods are of commercial importance and are well-known. Since they do not fall directly within the province of this work they will not be discussed in detail.

The change of reluctance of a magnetic circuit has been effectively applied to measurement in devices in which the flux density is measured directly, instead of employing that flux to induce a current. These devices can measure static magnitudes.

One gage, representative of the type, has been applied to the measurement of thickness of iron or steel plates.

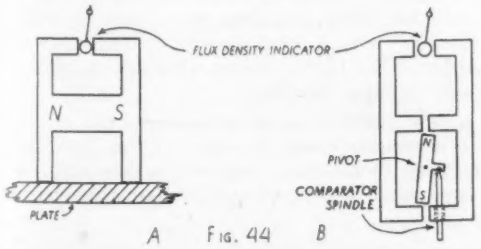


FIG. 44

The pick-up employed consists of a magnet, either a d-c.-excited electromagnet or a permanent magnet, so constructed that the specimen of plate being measured may be caused to shunt a portion of the magnet circuit. The shunting effect of the plate is proportional to its thickness, and the flux density so reduced is measured. Such a system can be applied to plates of considerable thickness, whereas the eddy-current or the variable-inductance types often become insensitive if the thickness of the plates exceeds about one-fourth inch. Fig. 44A illustrates the principle used in the plate-thickness gage; Fig. 44B illustrates a gage employing somewhat the same principle, but used for measuring small movements or as a comparator gage. In these gages, the measurement of flux density may be made by any desired means; it often is convenient to employ a bismuth conducting element, which has the peculiarity that its resistance is changed by the magnetic field. [71, 72]

§5. Definitions, Formulae, and Theory

The theory and the definitions contained in the body of this chapter, while accurate and descriptive, do not include sufficient detail for serious study or for design of equipment. For the use of the worker who wishes to evaluate critically the existing magnetic gaging circuits or modify them, or to design circuits, these paragraphs contain more detailed information, formulae, and data on alternating-current circuits.

Definitions:

Inductance is that property of an electric circuit or of two neighboring circuits which determines the electromotive force induced in one of the circuits by a change of current in either of them.

Self-inductance is that property of an electric circuit which determines, for a given change of current in the circuit, the electromotive force induced in that circuit.

Mutual inductance is the common property of two associated circuits which determines, for a given rate of change of current in one of the circuits, the electromotive force induced in the other.

The coupling coefficient is the ratio of the mutual or common impedance component of the two circuits to the square root of the product of the total impedance components of the same kind in the two circuits.

The impedance of a portion of an electric circuit is the ratio of the effective value of the potential difference between the terminals to the effective value of the current, there being no source of power in the portion of the circuit under consideration.

Admittance is the reciprocal of impedance.

Reactance is that component of the impedance of the circuit which is provided by the inductance (or capacitance); it varies directly as the frequency of the exciting current. Inductive reactance may be computed by this relation:

$$X_L = 2\pi fL$$

where X_L is the inductive reactance in ohms, f is the exciting frequency, and L is the inductance in henries.

The permeance of a portion of a magnetic circuit is the ratio of the magnetic flux through any cross-section of that circuit to the magnetic potential difference between two equipotential surfaces taken within the portion under consideration.

Reluctance is the reciprocal of permeance.

In practical electric circuits, resistance and capacitance are present, as well as inductance, so that in computing impedance all three components must be considered. In a series circuit, the impedance is the vector sum of the ohmic resistance and the difference between the two reactances. As in this relation:

$$Z = [R^2 + (X_L - X_C)]^{1/2}$$

in which Z represents impedance in ohms, X_C capacitative reactance, the other terms as previously defined.

The inductance of a coil with an iron (or other magnetic material) core may be computed approximately from the empirical formula here given, if the core contains no air-gap:

$$L = (3.2 \times N^2 \times \mu \times A)/(d \times 10^8)$$

In this formula, N represents the number of turns of wire

(Continued on page 366)

(71) Harry Moore *et al.* British Patent No. 378,983.
(72) F. K. Floyd. U. S. Patent No. 2,292,113.

ELECTRON TUBES—Their Principles and Their Instrumentation Applications

By ANDREW W. KRAMER, Managing Editor, *Power Plant Engineering*, Chicago, Ill.

XVIII. PHOTOVOLTAIC CELLS, THEIR CHARACTERISTICS AND HOW THEY WORK

The photovoltaic cell* which has come into use during the past few years operates upon the principle that an e.m.f. is created in an electrolyte or across a set of electrodes when the electrolyte or electrodes are illuminated. Thus with a device of this kind no other source of potential is necessary—it provides its own. Several types of these cells are commercially available. The "Photox" made by Westinghouse is a copper oxide cell consisting of a copper disk oxidized on one surface with a transparent film of metal deposited on the oxide. The Weston "Photronic" cell consists of a thin metal disk on which is deposited a film of light-sensitive material. The metal disk is the positive terminal while a metallic collector ring in contact with the light-sensitive surface is the negative terminal. The element in

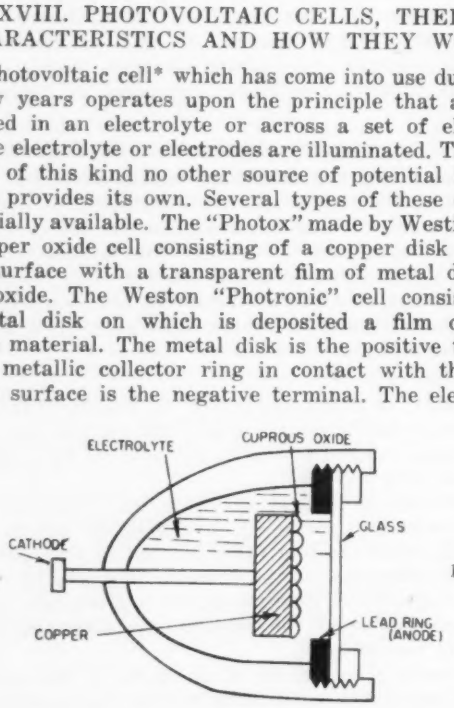


Fig. 118.

the General Electric photovoltaic cell consists of a layer of selenium deposited on the surface of a steel plate. Over this layer of selenium, two transparent layers of conducting metal are deposited, this making the negative terminal of the cell. The Photovolt Co.'s "Eletrocell" consists of a semi-conductive layer, deposited on the surface of an iron disk and overlaid by a transparent conducting film.

As will be noted, although the materials differ, the fundamental principle involved in all of these photovoltaic cells is the same. All of them make use of the Becquerel effect, discovered over a hundred years ago. Becquerel noticed that if two similar electrodes were immersed in an electrolyte and one of them was illuminated more than the other, the device developed a voltage.

The mechanism of the photovoltaic cell is not nearly as well understood as is that of the photoemissive tube. It would seem logical that the fundamental principle involved in these cells is photoemission nad attempts have been made to explain their action on this basis but these attempts have not generally been successful. In a number of instances the results seem to contradict this theory.

Despite the uncertainty regarding its action, the development of these photoelectric devices has gone forward rapidly and a number of different types are in successful commercial use. At the present time their greatest use is as light meters and as exposure meters in photography but they are also in use in many industrial applications such as the smoke indicator referred to in the preceding article.

In many ways these cells constitute a special class of electronic† devices which may well prove of great consequence in future years. For these cells are man's most successful attempt, thus far, in converting power from the sun into useful energy directly. True, their efficiency as a conversion device is very low, only some 0.6%, but it may be possible that new discoveries will enable us to raise that. Even with these cells, minute as they are, it has been possible to drive a small electric motor. This was accomplished in the General Electric Research Laboratory. The motor was a tiny affair rated at only four ten-millionths of a horsepower but in direct sunlight four of these small photovoltaic cells operated it at about 400 r.p.m. Naturally it must not be inferred that this method will be improved to such an extent as to make possible the commercial production of electric power direct from the sun, but it is interesting from a scientific standpoint and some day somebody may make a more efficient cell. On the basis of the cells used by the General Electric Co. in this experiment some 20 sq. ft. of active surface would be necessary to pro-

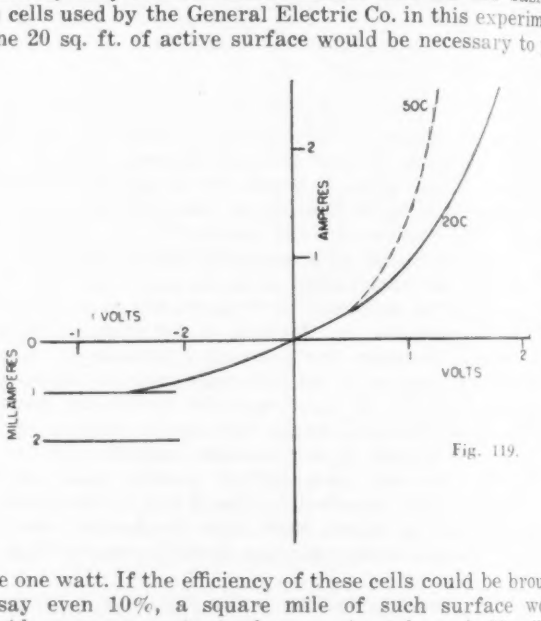


Fig. 119.

duce one watt. If the efficiency of these cells could be brought to say even 10%, a square mile of such surface would provide a power output of approximately a half million kilowatts from the sun.

Aside from this aspect of their use, these devices will find increasing usefulness in many commercial and industrial applications. Their power yield per unit of light is high as compared to the vacuum phototube and where frequency is not a limiting consideration they have many advantages over the vacuum phototube.

As already stated, the operation of these cells is based upon Becquerel's discovery that when two similar electrodes are immersed in an electrolyte and one of them is illuminated more than the other, a voltage is developed and if these electrodes are connected by a wire, a current will flow in this wire. This very principle was later incorporated in the cuprous-oxide electrolytic cell shown in Fig. 118. This cell, as will be noted, consists of a cuprous-oxide-coated copper electrode and a lead electrode, immersed in a lead nitrate electrolyte. Light shines through a glass window on the cuprous-oxide surface.

With a low resistance galvanometer, the current from this cell is a strictly linear function of the illumination and it may be used to measure lumination intensity but at the present time the dry type of cell is used almost exclusively for this purpose.

The Dry Type Photovoltaic Cell

In considering the action of the dry type of cell, we will begin with the copper-oxide cell. If clean copper is subjected to a proper oxidizing treatment, a reddish crystalline layer of cuprous-oxide forms on its surface. This is well-

*Also known as blocking-layer cell; sometimes called barrier cell.—EDITOR.

†Dry-disk photocells are NOT electronic devices because they lack the essential: "a vacuum or gaseous *space* in which electric current is carried by *free* electrons." See Dr. Slepian's masterly final-word pronouncement on this subject in *Instruments*, April 1943, pages 186-187, 210-212. However, we let Mr. Kramer's qualification stand because he naturally is the one to decide on the types of devices to include in his own serial on "electron tubes."—EDITOR.

known and there is nothing mysterious about the process, but it has been found that the dividing surface between the mother copper and the oxide exhibits some very remarkable properties. It is a highly efficient rectifier of alternating currents for low voltages. As shown by the graph in Fig. 119 for voltages up to about three (maximum), a few square inches of surface, amperes pass in the permeable direction while only milliamperes pass in the opposite direction. In using this surface as a rectifier, the mother copper forms one terminal and some soft metal such as lead or tinfoil pressed against the surface of the oxide forms the other. In commercial forms, the outer surface of the oxide is copper plated and this forms the other terminal. It might be thought that by using two copper surfaces as the terminals in this manner the rectifying action would disappear, but this is not so: the rectifying action seems to depend upon the peculiar bond between the cuprous-oxide and the metal upon which it is formed. This rectifying property is effective only up to about 3 volts. If too much inverse voltage is applied the cell overheats and the action is spoiled by the cracking of the oxide away from the copper.

The rectifying action of the copper oxide cell was known before its photoelectric properties were discovered. Here

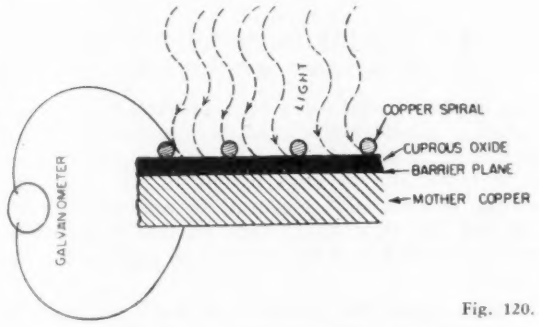


Fig. 120.

again it will be noted, as was the case with electron tubes, rectification is a fundamental property of the photovoltaic cell; indeed, rectification seems to be a fundamental property of most electronic devices. In 1926 Grondahl showed that the copper-copper oxide surface could be used as a source of photovoltage. He pressed a spiral of copper wire against the surface of the oxide with space between the turns so that light could shine through onto the oxide and found that when the oxide was illuminated a current flowed through a galvanometer connected to the mother copper and the spiral as in Fig. 120.

Direction of Electron Flow in Cells

An interesting thing about these oxide cells is that when they are used as rectifiers, the direction of electron flow is from the copper to the cuprous-oxide; that is, with an impressed voltage, electrons can pass the boundary from the copper to the cuprous-oxide easily but are blocked when they try to pass the barrier in the reverse direction. When the cell is used as a source of photovoltage, that is when light produces the voltage in the circuit, electrons flow across the boundary from the oxide to the copper! This anomalous action has not been explained and the operation of these cells is not fully understood despite their increasing commercial use.

Characteristics of Commercial Types of Cells

As pointed out before, there are a number of different forms of these cells on the market. The copper-cuprous oxide cell just described is sold by the Westinghouse Electric & Mfg. Co. under the name of "Photox." This is essentially the same as the unit described above except that the oxide is covered with a thin layer of gold which is transparent to light, the gold serving as one of the electrodes.

The General Electric light-sensitive cell consists of a layer of selenium deposited on the surface of a steel plate, a little over one square inch in area. Over this layer of selenium, two transparent layers of conducting metal are deposited, making the negative terminal of the cell.

In Fig. 121 is shown a master curve of the characteristics of the General Electric photocell. This chart shows the voltage current data plotted at constant values of temperature for various values of illumination. Superimposed on these curves are the voltage-current relations for a full range of resistance values which are shown as straight lines drawn out from the origin. At any illumination, the external potential can be determined for all values of current or resistance, and hence, the power available under these conditions. The variations of the voltage-current characteristics are given at −3°C. and +40°C. for 20 and

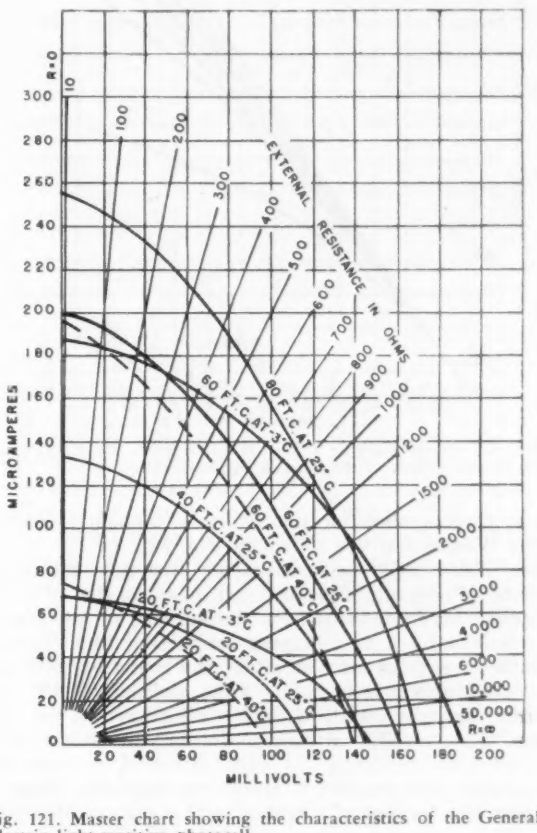


Fig. 121. Master chart showing the characteristics of the General Electric light-sensitive photocell.

60 foot-candles. From these curves, any desired information on the cell may be derived within the given range of illumination.

An example may serve to clarify the use of these curves. Suppose the current output at 700 ohms is desired from an illumination of 80 foot-candles and at a temperature of 25°C. The 700-ohm resistance line crosses the 80-foot-candle voltage-current curve at a point which has a current coördinate of 150 microamperes, and a voltage coördinate of 105 millivolts. Therefore, the photocell will deliver 150 microamperes on an external resistance or equivalent load of 700 ohms. This means that the external power is $150 \times 0.105 = 15.8$ microwatts.

The Weston "Photronic" cell consists essentially of a thin metal disc on which there is a film of light-sensitive material, such as iron selenide. The metal disk forms the positive terminal and a metal collector ring in contact with the light sensitive surface forms the negative terminal. The photocell is contained in a case having a window of glass or quartz depending upon whether the photocell is to be used only in the visible or infra-red regions of the spectrum, or in the ultraviolet.

The current output of the Weston photocell, as it is of other makes of photovoltaic cells, is linear for low resistance. This holds for illumination intensities from zero to as high as 10,000 to 15,000 foot-candles, hence, they serve very effectively as light meters. The current output of the average cell is about 1.4 microamperes per foot-candle of illumination uniformly distributed over the sensitive surface and with a low external resistance. The output of the average cell is 120 microamperes per lumen, but of course this varies with the amount of external resistance in the

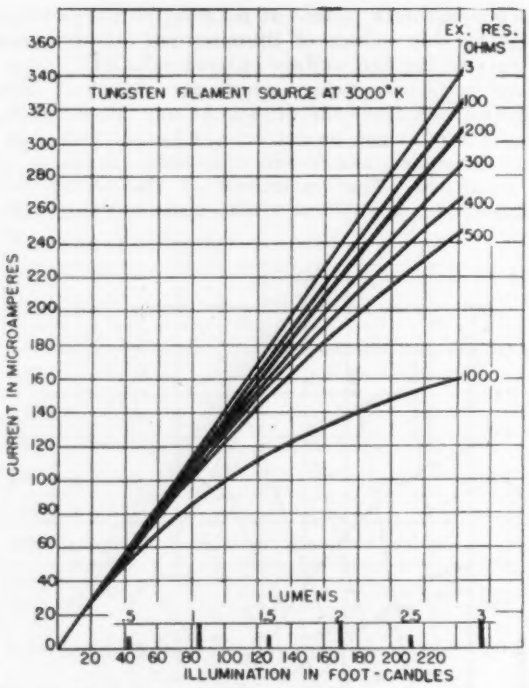


Fig. 122. Chart showing the effect of external resistance upon the current output of the Weston Photronic cell.

circuit. Curves showing the effect of external resistance for the Weston cell are shown in Fig. 122.

The "Electrocell" self-generating dry-disk photoelectric elements (Photovolt Corporation) also consist of a semiconductive layer deposited on the surface of an iron disk and overlaid by a transparent conducting film. These are available in various sizes in either the round or rectangular form. They generate up to 0.6 volts and deliver 480 microamperes per lumen with negligible resistance in the circuit.

The "Electrocell," although similar in construction to other photovoltaic cells, has quite different characteristics, particularly with respect to frequency response. Tests indicate that the Weston "Photronic" cell is not suitable for use at audio frequencies such as are used, for example, in talking pictures. Its frequency response diminishes with increasing frequency due largely to the shunting effect of the internal capacitance of the cell, which is of the order of 0.5 microfarad, and is approximately inversely proportional to it. If the response at 60 cycles is assumed 100%, that at 120 cycles will be about 58%, that at 240 cycles will be about 30%, at 1000 cycles about 6.4% and so on as the frequency increases. This reduction in current output of the "Photronic" cell with high incident light frequencies is quite characteristic of photovoltaic cells in general but the "Electrocell" differs in this respect. These units have a high "dynamic" response and their electrical performance drops to only 40% at frequencies as high as 6000 cycles per second. This makes these cells applicable for sound production and recording. The slight decrease in output at high frequencies causes some attenuation of the higher notes, but since the effect is caused by the capacitance of the elements, it can be offset by using a suitable inductive reactance in the circuit.

This difference in the dynamic response of these different photocells is due to a difference in the proportion of photoconductive effect. The true photoelectric effect as exhibited at the active surface of the vacuum phototube has no appreciable time lag; the electrons are emitted simultaneously with the incidence of light. The dynamic response of such a tube is independent of frequency of fluctuation of the impressed light beam. The light may fluctuate in intensity millions of times per second and the variations in phototube current will be exactly the same as when the frequency of light variation is a few cycles per second. The dynamic response of such vacuum phototubes has no relation whatever to frequency.

The fact that the response of photovoltaic cells does vary with frequency seems to indicate that the current flowing in these cells is of secondary origin. The process of producing this current takes a comparatively long time, quite a "large" fraction of a second. It is this fact that makes it evident that the action in these cells is not photoelectric in the true sense. Quite probably there is a small true photoelectric current which appears simultaneously with the incident light but this current is so small compared to that which results from secondary action that its effect on the total response of the cell is not discernible. Even in those cells with a high dynamic response, the lag is still such as to suggest that the current is largely of secondary origin.

We have gone into some detail in discussing these photocells because they are extremely compact and useful devices. The fact that their current output is sufficiently high to operate galvanometers, measuring instruments and relays without additional amplifiers, makes them very desirable for certain applications. For all relay work the cell response is so much more rapid than it is possible to make such relays that it may be considered instantaneous. By actual test the speed of response of the Weston "Photronic" cell was sufficiently rapid to record the passage of a rifle bullet through a beam of light incident upon the cell.

XIX. THE DYNATRON PRINCIPLE AND THE ELECTRON MULTIPLIER

In the material which has been presented in the preceding articles, consideration has been given to details of design and principles of operation of a number of different types of tubes and to some extent to their applications. Knowledge of details is essential to an understanding of any subject but in a study such as this it is possible to become so absorbed in details as to lose sight of the picture as a whole.

This is precisely the situation we want to avoid. There are many reference books available and still more magazine articles and technical papers, not to mention innumerable manufacturers' catalogs and bulletins which present the datailed theory, design, construction and application of all types and sizes of electron tubes far more comprehensively than we could possibly do so here. Such material, however, is written largely for those who already have a good basic knowledge of the subject and quite often is too advanced for those who have not had occasion to use electron tubes or who have not studied their basic principles.

Details of applications will be considered in later articles, but the primary purpose of this discussion is to present a picture of the subject of electronics as a whole, to impart its philosophy and to correlate its various branches. The electron tube represents something far more than merely a new device or tool for the electrical engineer; it represents a new point of view, a new approach to methods and principles.

Consider, for example, such a commonly-used device as the a-c. radio receiver. Before 1920 the idea of transforming alternating current into pure direct current by means of non-rotating equipment was almost unthinkable. Then came the radio receiver with its electron tubes and the need for pure direct current in their plate circuits. At first this necessary direct current was derived from dry batteries—"B" batteries—but these gave maintenance troubles and so an effort was made to obtain a source of direct current from the alternating-current mains. The first attempts at this were feeble, owing largely to a lack of suitable rectifier tubes, but once the principle involved was understood, development was rapid. Some of the first so-called B-battery eliminators used rectifiers of the electrolytic type but these were soon superseded by units employing thermionic rectifiers.

The problem involved here was more than mere rectification. Simple rectification of an alternating current such as that represented by *A* in Fig. 123 produces not a smooth unvarying current such as that required by a radio receiver but a pulsating current such as that represented by *B* in Fig. 123, or even where full wave rectification is used,

a pulsating current such as that represented by the wave C. The production of a smooth unvarying current from a rectified output such as that represented by *B* or *C* implies the concept of storage—storage of electrical energy. It is obvious that at the times t_1, t_2, t_3, etc., in wave *B*

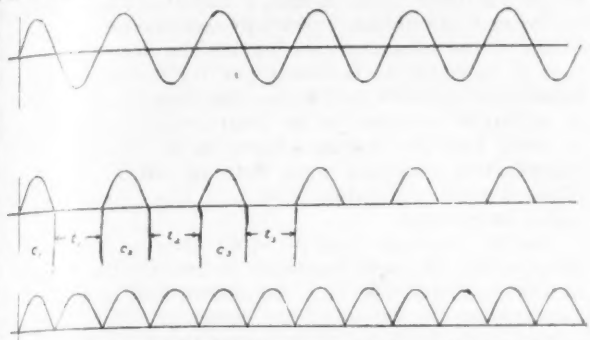


Fig. 123. Simple rectification does not result in a direct current as the term is ordinarily understood. It results in a pulsating current which although uni-directional is unsuitable for many purposes.

there is no source of e.m.f. in the circuit, and if a current is to exist at these times, it must be derived in some way from pulsations C_1, C_2, C_3, etc. In other words, some of the energy represented by the pulsations C_1, C_2, C_3, etc., must be shunted into some sort of a storage reservoir and held there until the times t_1, t_2, t_3, etc., and then released. Ordinarily the concept of storage of electricity is unthinkable; in the power industry it frequently is pointed out that electricity is the one thing that cannot be stored: it must be utilized the very instant it is generated and that is why public utility companies have to consider such things as load factor and diversity factor and many other tangible elements so confusing to the general public. For such short intervals of time as represented by the intervals between successive half-waves of ordinary alternating current, i.e., 1/120 sec., it is entirely possible to store electricity in capacitors. Capacitors alone, however, are not enough. Such condensers obviously must be connected permanently into the circuit in order that the energy stored in them during the times C_1, C_2, C_3, etc., may be released at the times t_1, t_2, t_3, etc., some sort of a delay arrangement must be introduced. This delay is provided by inductance coils or "chokes." The effect of inductance, it is well-known, is just exactly opposite to that of capacitance in an electric circuit.* One (capacitance) causes the current to lead the impressed voltage whereas the other (inductance) causes it to lag behind the impressed voltage. By suitably combining inductances and capacitances in a network, a "filter" circuit is set up which brings about the

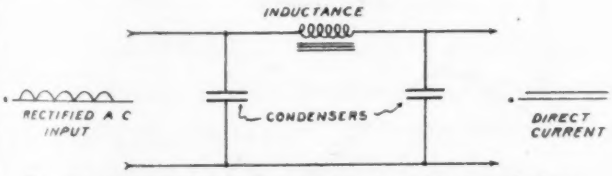


Fig. 124. By means of a filter circuit such as this the pulsations of a current such as represented in Fig. 123 are ironed out and a pure direct current results.

result desired; i.e., during the active portion of the cycle (times C_1, C_2, C_3, etc.), a portion of the energy is stored up in the capacitors and the inductance and then released at the times t_1, t_2, t_3, etc. Such a filter circuit is shown in Fig. 124.

This is a comparatively simple filter; others are more complicated but in general the theory of their operation is the same. Both the inductance and the capacitors possess the ability to store electric energy, the former in the form of the electromagnetic field, the latter in the dielectric field.

*The fundamental properties of inductance and capacitance and their effects in electric circuits are fully discussed by the author in "Electricity—What It Is and How It Acts," Volume I, and also in "This Thing Called Power Factor" published by Technical Publishing Co.

While the amplitude of the rectified a-c. wave is increasing, energy is being stored both in the inductance and in the capacitors, after the peak has been reached and the amplitude of the rectified wave begins to decrease, the stored-up energy is released and this fills in the valleys between the rectified humps. The filter, it will be evident, is the electrical counterpart of the flywheel in mechanics.

Our purpose in introducing this discussion of filter circuits here is not so much to explain the action of these circuits as it is to show how the electron tube has extended the usefulness of already-known principles and properties of circuit. Before the advent of electronics alternating current and direct current were distinct and entirely separate — interconvertible only through means of rotating equipment: motor-generators and rotary converters. Today, alternating- and direct-current circuits are combined and interconnected in all sorts of ways; in some instances as in the automobile radio receiver, direct current from the battery is transformed into alternating current through the agency of the vibrator and this alternating current at high voltage is again converted into direct current. In other words, limitations which once were insurmountable no longer exist.

A similar condition exists with respect to change of frequency. Frequency at one time, except as circuit operation was affected by usually objectionable harmonics, was something that was unalterably determined by the generator. Frequency change could be obtained only by means of rotating frequency changers. Today, because of the electron tube, frequencies can be changed or varied over wide ranges by purely static equipment. This, naturally, provides entirely new possibilities in the use of certain types of equipment. A synchronous motor, for example, can be started and brought up to any speed and operated at that speed merely by supplying the proper frequency from electron-tube equipment.

These developments, even though they have not reached huge commercial proportions, nevertheless require a new point of view of the electrical art. Because of the science of electronics and the electron tube the electrical art becomes a much more homogeneous whole.

Now that we have discussed in some detail various types of tubes and their characteristics, let us review them briefly. To begin with, there was the two-electrode tube which gave the fundamental property of rectification. Next came the triode with its valuable property of amplification. The effect of introducing inert gases into both of these tubes was considered at length and was shown to alter the character of the triode completely.

The result of amplification with certain types of tubes was next shown to be oscillation, that is, the generation of alternating current of any frequency. The principle of oscillation, however, valuable as it might be in certain respects, was shown to introduce limitations in the use of triodes as amplifiers, so schemes for neutralizing circuits were developed and these were described. The neutralized amplifier circuit, however, was an expedient developed to overcome certain difficulties—a makeshift, so to speak, which itself introduced objectionable limitations. So a new type of tube was developed, the four-electrode or screen-grid tube which nullified the interelectrode capacitance effect and therefore made neutralization unnecessary.

The four-electrode tube, however, was characterized by what is known as secondary emission and so, finally, to prevent this, still another electrode, the suppressor grid, was introduced. Thus the pentode came into existence.

These constitute the principal ordinary tubes but as was shown there were others, the x-ray tube and the cathode-ray tube, which utilized the principles involved in these others but because of their specific functions had to be considered separately. Finally, we discussed the photoelectric tube and the principles involved in photoelectric emission (and for good measure we threw in the photovoltaic cell—which isn't a tube).

Thus it is evident that these tubes, though each possesses certain special functions, are related either by virtue of

the principles involved or through evolution. The pentode is related to the diode through all the intermediate members of the family and, though its special function is that of amplification, it is fundamentally a rectifier.

The phototube, obviously, is in a class of its own since it possesses a specialized function but here again we find a relation with other tubes such that it is virtually impossible to think of one without the other. The most sensitive phototubes (but not photovoltaic devices) would be almost useless were it not for the thermionic amplifier. The output of the ordinary phototube is so small that only the most sensitive and high-resistance relays can be controlled by it, without some type of intermediate amplifier. That is why in all applications where phototubes are used, one or more thermionic amplifier tubes will be found in the circuit.

Consider a simple circuit, such as that shown in Fig. 125 where a phototube is used to operate a simple magnetic relay through a triode amplifier. The grid-cathode path

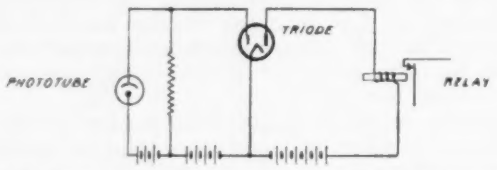


Fig. 125. Showing the use of a triode amplifier in adapting the phototube to the operation of a low-resistance power relay.

of the triode is of a high resistance—many megohms if the grid is negative. The plate circuit, on the other hand, has a relatively low resistance, of the order of a few thousand ohms. These features admirably adapt the circuit for connecting a phototube to a power relay. The phototube has a low resistance of many megohms whereas the ordinary power relay has a low resistance—from a few ohms to a few thousand. Although the output of a phototube may be as high as 30 volts, its resistance is of such a high order that it would be short-circuited by the average power relay connected across it. In other words, the phototube cannot deliver sufficient power to operate a low-resistance relay directly.

If, however, an amplifier circuit is introduced between the phototube and the relay as shown in the diagram, a different condition prevails. Here, if the phototube changes the grid voltage of the tube, the plate current of the tube will operate the relay. The tube acts as a transformer in which both the current and the voltage are stepped up. The power amplification obtained in this way is easily of the order of 2000 to 3000 times.

This, it will be obvious, is only a typical example of countless other applications of the thermionic amplifier, but it serves to show how the amplifier gave new life to an effect which had been known for many years. The photoelectric effect was discovered many years ago but it was too feeble to be of any practical use until the thermionic amplifier came into existence.

The value of the thermionic amplifier is almost beyond conception. The sound of a fly walking on tinfoil can be made to shake a cathedral. In the same way tiny variations in the output voltage of a generator can be made to operate powerful equipment used to stabilize that voltage. The possibilities are endless. In fact, in some communication systems the amplification is so great that the granular structure of electricity becomes objectionable: the noise created by the passage of individual electrons becomes a limiting factor in the operation of these circuits. Astonishing as this may seem, it is a factor of decided importance in the design of sensitive circuits.

The matter of oscillation generation was described in Chapters X and XI. The full importance of this process is more fully appreciated by the communication engineer than by power men at the present time, since electron-tube oscillators form the basis of nearly all communication circuits. No mention was made, however, of the methods by which electron tubes modulate electrical oscillations to suit them to whatever purpose we desire. In a typical radio broadcast transmitter, voice currents created by one of several possible types of microphones (some of which are entirely electronic in their action) are amplified by a series of ordinary amplifying tubes (the speech amplifiers) and the output of these is impressed upon modulator tubes the function of which is to mold the high-frequency output of the oscillator tubes in such a way that these oscillations will vary in amplitude exactly in accordance with the variations of the voice currents leaving the microphone.

It is said that in the meat packing industry everything is used except the squeal of the pig. But, as was pointed out in an earlier chapter, in the electron tube even the squeal is used. For the squeals issuing from De Forest's early regenerative receivers were nothing but a manifestation of oscillation generation and this has proved of inestimable importance.

Another example may be cited showing the use of an effect which in some instances is undesirable. In the discussion in Chapter XIV, it was shown that secondary emission limited the action of the screen-grid tube and so the pentode was developed to overcome this limitation. In some types of tubes, however, this principle of secondary emission is actually put to good use. One of these is the Dynatron, a special arrangement of the triode first introduced

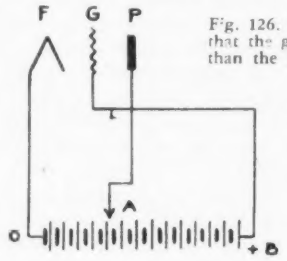


Fig. 126. The Dynatron circuit. Note that the grid is at a higher potential than the plate.

by A. W. Hull. In the Dynatron circuit, the triode is connected so that the grid is at a higher potential than the plate as shown in Fig. 126. Under such conditions it is evident that any secondary electrons produced at the plate will be drawn to the grid by virtue of the higher positive potential existing there.

If, with a circuit of this kind, the plate potential is gradually increased from zero by moving the contact *A* to the right, the plate current will increase at first, then, as the plate voltages rise still further, secondary electrons will be produced at the plate and as these are drawn to the grid, they constitute a reverse plate current. At a point of plate potential where as many secondary electrons are produced as there are primary electrons, the net plate current is zero. Then, as the plate becomes still more

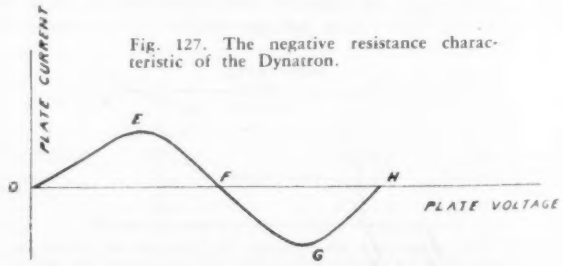


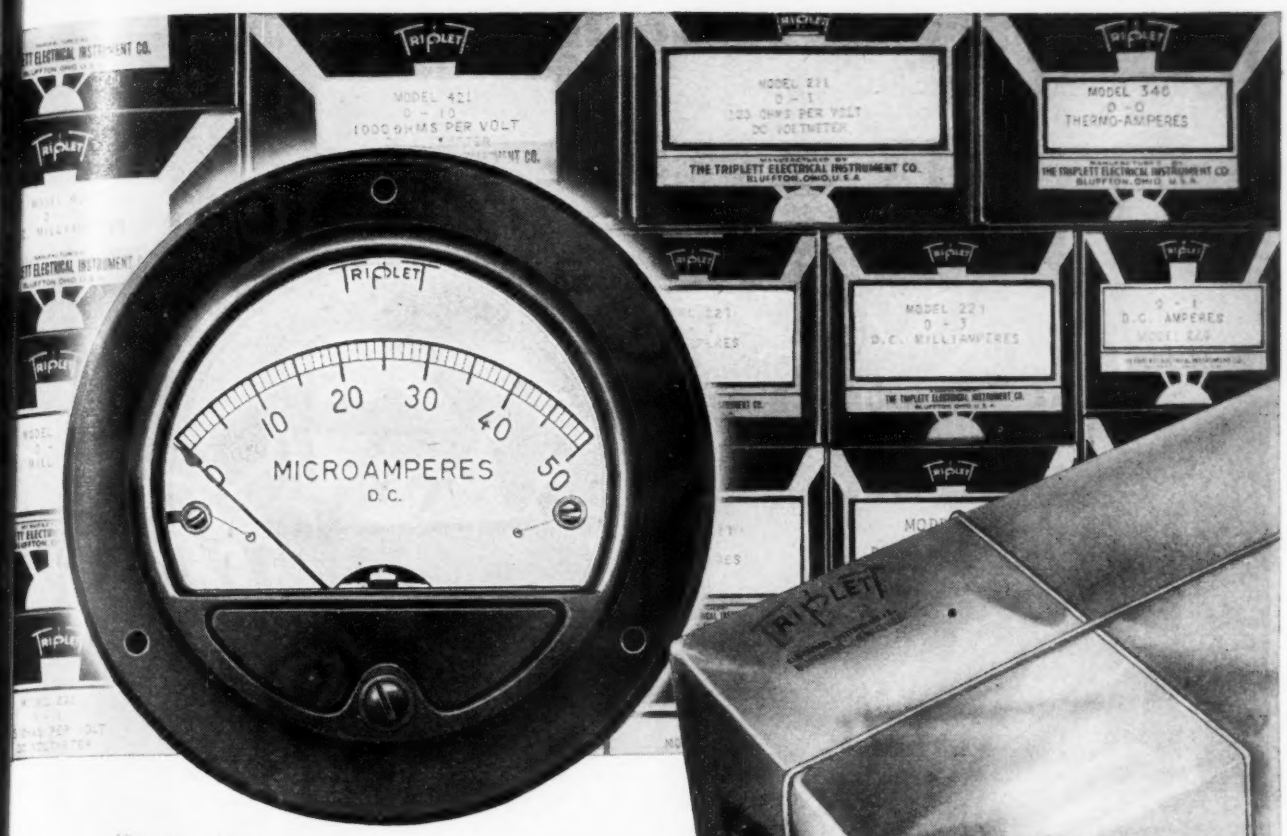
Fig. 127. The negative resistance characteristic of the Dynatron.

positive, the number of secondary electrons produced will exceed the number of primary electrons and the plate current actually reverses.* Finally, as the plate approaches its maximum positive value (i.e., the same potential as the grid) the secondary electrons will no longer be attracted to the grid and the plate current again becomes zero. This action is shown in Fig. 127.

The peculiarity of that part of the curve from *E* to *G* is the basis of the action of the Dynatron; an increasing plate potential results in a decrease of plate current. This portion of the characteristic therefore exhibits the property of what is known as negative resistance. The Dyna-

(Continued on page 354)

*In this case each primary electron is responsible for the emission of two or more secondary electrons.



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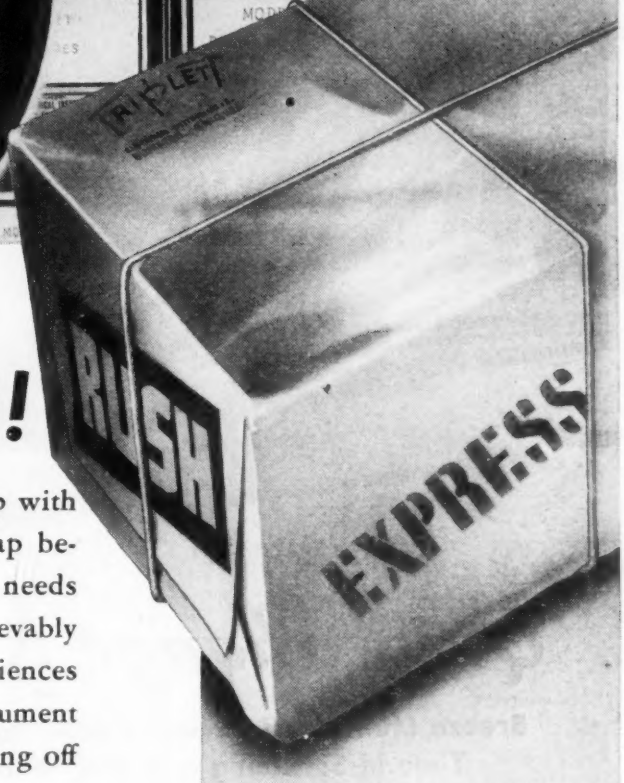

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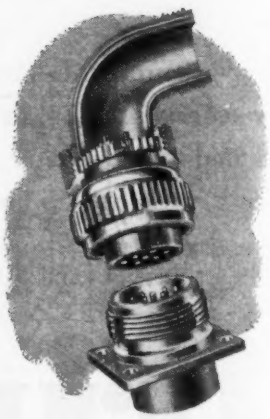

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Vol. III, No. 6 M. F. Behar, Editor June 1944

Flash-charging Tachometer Generators

By RANSOM H. BURT, Jacksonville, Fla.

IN overhauling synchronous type tachometer generators a certain percentage is found to have become inoperative by reason of magnets becoming weak either from use in the airplane or during the process of overhaul. To shops just starting up or which cannot get the equipment to charge these magnets because of location or war-time red tape, this presents a real problem. A way has been found to overcome this difficulty that is fairly effective in all cases. While it is not a new method, it may be new to some people in the business of overhauling aircraft electrical instruments.

The process consists of momentarily applying a high voltage to the stator winding of the generator to be charged. This can be done after overhaul or before, and the generator is assembled before charging. The rotor has to be lined up before charging. This is done by applying a low voltage to the winding of the stator. An aircraft battery of 12 volts is used for this purpose.

Procure an ordinary plug of the type used on the generator in the airplane. Solder two lengths of No. 14 or No. 18 insulated wire to the terminals of the plug. The wires should be approximately five feet in length. On the other end of the wires attach medium-size clips, marking one with red paint so the correct polarity can be observed.

A d-c. voltage supply is required in the order of 160 volts. A bank of six or eight 24-volt aircraft batteries connected in series may be used for this supply.

To charge the generator, first make sure that the rotor is free to turn with the fingers, or trouble will be encountered in lining it up. To line up, insert the plug that was made up in the generator receptacle and connect the clip marked with the red paint to the positive side of the 12-volt battery. Watch the shaft of the generator and touch the free clip to the negative terminal of the battery. The shaft should flip quickly to another position and remain there, indicating that the rotor is properly lined up. If it doesn't do as described, turn the shaft a quarter turn and repeat the above operation. Care should be taken not to move the shaft after lining up.

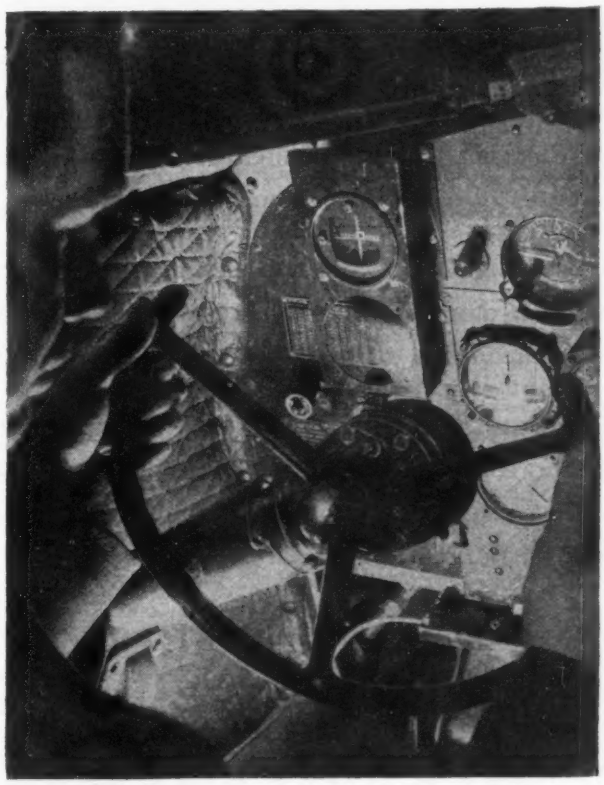
With the batteries connected in series (use six to start and if not enough add the other one or two) remove the plug from the receptacle and connect the clip with the red paint to the positive terminal of the battery bank and the remaining clip to the negative terminal. *The plug must not be left in the generator when the wires are attached to the high voltage of the battery bank as this will burn out the stator winding.* Insert and withdraw the plug with a motion as rapid as possible to prevent injury to the stator winding. Do this two or three times and install generator on test stand and check for voltage output. In most cases the voltage will be found to be higher than required and can be brought down by short-circuiting the terminals while generator is in motion on the test stand.

This method has been found to be highly successful on Pioneer and General Electric Tachometer generators, but is not recommended for use on Kollsman.

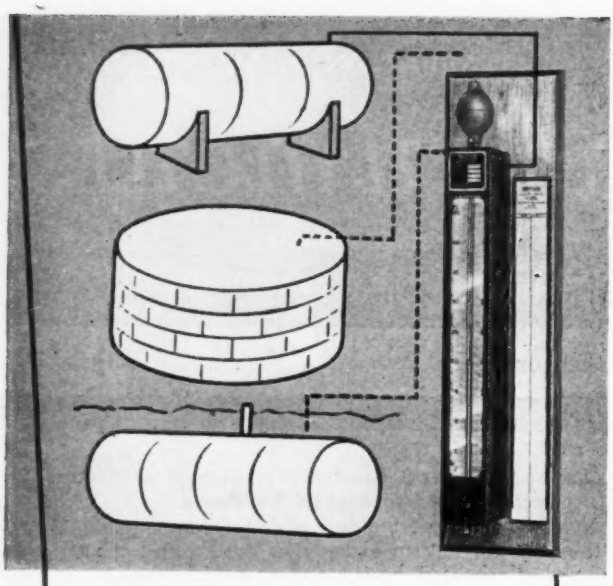
Note: It is suggested that every precaution be taken to retain the magnetism already in the generator during the process of overhaul, by the proper use of keepers, etc.

Indicating Instrument Method Helps Combat Pilots Land "Blind"

VISUAL indications—instead of audible dots and dashes—are given by a cross-pointer blind-landing instrument which guides pilots back to their home airfields and enables them to hit runways "on the nose" even when they are blacked out by war or weather. These cross-pointer indicators are in production at the Westinghouse Meter Division, Newark, N. J., according to Tom Turner, manager, and are now being built into combat planes and trainers. According to the Westinghouse announcement, military sources report countless instances of blind landings where



With this cross-pointer indicator (mounted experimentally) combat pilots get directions for flying the hazardous last mile earthward to airports blacked out by war or weather, merely by watching the two crossed pointers. The indicator translates visually radio signals from the ground, to guide the pilot down the proper glide path and to keep them from veering to right or left. By keeping the pointers crossed in the center of the dial, pilots can touch their wheels on the runway within fifty feet of a preselected spot.



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air crews have saved themselves by using this visual instrument for guidance during their hazardous last mile earthward; some of these sources report landings in which pilots were able to "touch down" on the unseen field within fifty feet of a pre-selected spot.

"During the Italian campaign," Mr. Turner said, citing a typical case, "nine bombers with 90 men, operating out of North Africa, returned from a mission to find their Tunisian base completely fogged in. Instructions by radio told them to make for an Algerian port, as their Tunisian terminal was not then equipped with instrument landing transmitters.

"They reached the alternate field after nightfall, and were compelled by dwindling gas supplies to make short work of their landings. The indicator guided them quickly and precisely down to a base unknown to them, amid rough, dangerous terrain. Landing there without aid of the indicator might easily have proved disastrous."

The War Department and Civil Aeronautics Administration jointly are pushing tests and experiments to hasten

CLOSE-UP OF NEW INDICATOR—At the Westinghouse Meter Division, Newark, N. J., final adjustments are being made on the sensitive instrument, whose pointers remain crossed over the dotted lines as long as the pilot's descent is on course and is neither too shallow nor too deep.

installation of this instrument-type landing system at the country's one hundred leading airports, Mr. Turner disclosed, adding:

"Though it is not strictly a 'war baby,' the instrument has proved its value in the crucial tests of aerial warfare. It is the result of seven years' continuous research and development by the Westinghouse Elec. & Mfg. Co. and the Washington Institute of Technology, which worked with the U. S. Navy to originate a simplified device for taking the guesswork out of blind landing.

"The instrument visually translates directional radio signals which furnish continuous vertical and lateral guidance to the runway when visibility is so bad that a pilot cannot see beyond the wing tips of his ship."

Describing the instrument as "the most practical blind-landing indicator so far developed," Mr. Turner said it "not only assures accuracy and speed, both essential to a pilot trying to set his ship down safely on an unseen runway, but it frees him of such mechanical encumbrances as earphones, slide-rule, and paper-and-pencil work, such as must be utilized with earlier systems or when making a blind landing by dead reckoning.

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"With the instrument system," Mr. Turner pointed out, "the pilot gets all directions for descent merely by watching two crossed pointers and two signal lamps on his instrument panel. Commercial pilots say the day is in sight when this system for landing will prevent cancellation of 90 percent of flights now delayed because weather conditions at the airport of destination would prevent a safe landing." He gave this description of the new system:

The plane itself is equipped with two radio "landing" receivers which are tuned to the directional beams issued by the ground equipment. One receiver, responsive to the "localizer" or on-course beam, moves the vertical pointer on the instrument dial. The second receiver, which responds to altitude signals, operates the horizontal pointer.

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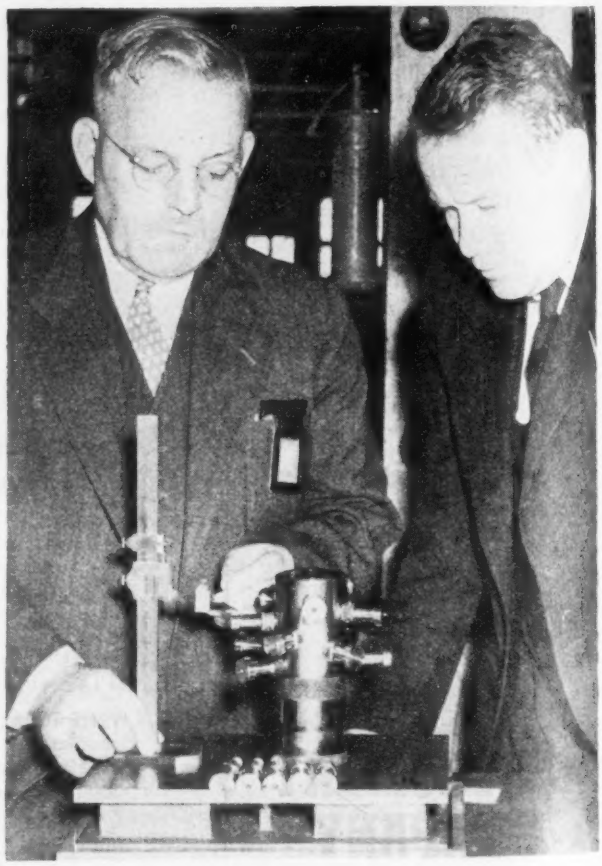
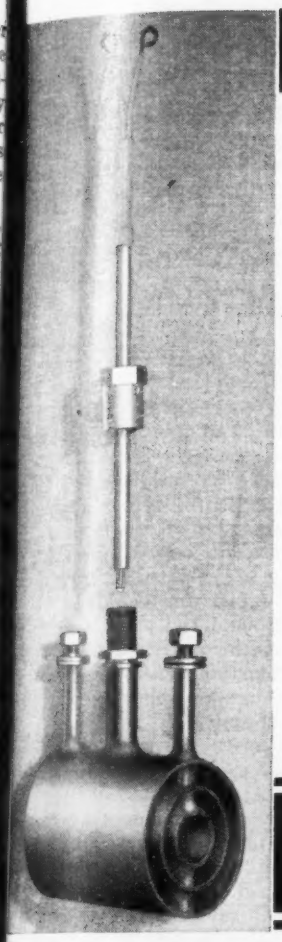


micrometer. L. S. Guetti *(left)*, machine shop foreman, and R. H. McNally, supply division supervisor, developed the training gage during lunch periods. Students in the shops manufactured it. Measurements are made on 18 different-sized plugs inserted in a dozen holes of varying heights. The gage itself can be moved one inch in 0.0001" steps. Here, Guetti demonstrates its use with a vernier height gage.



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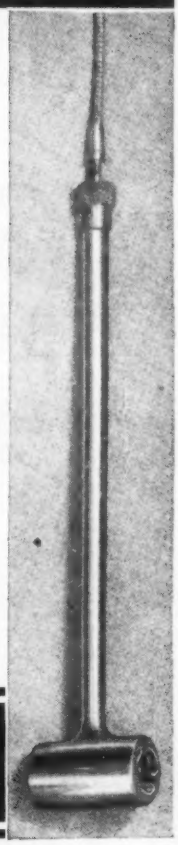

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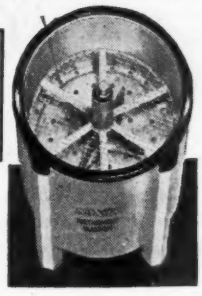

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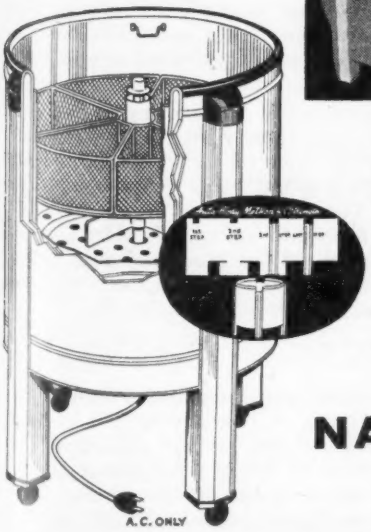

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tenna systems at and near the airport comprise the ground radio equipment. They emit beams which first indicate the pilot's approach to the field and then mark the field's boundary; establish the invisible glide path which leads to the runway; and signal directions for keeping the glide to the field neither too shallow nor too steep.

Vertical guidance—to maintain the position of the plane in relation to the runway—is provided by three of these transmitters.

One furnishes the "glide path," a radio beam which can be compared to the funnel-shaped ray thrown by a flashlight. The other two transmitters are "markers" whose beacons, transmitted vertically, light the lamps on the pilot's instrument panel via the plane's "marker" receivers. The first flash tells the pilot he is a few miles from the airport and he should prepare for the glide path by maintaining an altitude of 1500 feet. When a similar beam from the second marker lights the other lamp the pilot knows he has reached the boundary of the field.

The homing path, or "localizer," is produced by ultra-high-frequency radio transmitters feeding a pair of sharply directional antenna systems, consisting of two loops.

Signal strength emanating from the loops is almost equal if the plane is on course—"flying in" directly between them. This the vertical pointer of the instrument interprets by assuming an upright position. Should the plane wander to the left or right of the course, the corresponding signal predominates, causing the vertical pointer to veer in that direction, and in an amount roughly proportional to the distance the ship has flown off course.

The horizontal pointer remains in position—across the center of the dial—so long as the plane is gliding earthward at the correct angle. If the glide is too shallow, the pointer rises; if it is too steep, the pointer moves downward.

At Indianapolis and several other commercial airports and on Army and Navy flying fields, where the cross-pointer type landing system is in daily service, pilots learn quickly how to use it, Mr. Turner said. Already, thousands of our Army and Navy pilots have learned to use and depend on it as an "essential" in modern flight technique.

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The Guild Q&A Column

Conducted by F. H. HONEYCUTT, Guild Recorder

Q. We find many dials that need the background painted but do not need luminous paint. We would like to know of a method by which the luminous paint can be saved and still obtain a good painted background.

A. This can be accomplished by covering just the luminous paint with a water-soluble glue. The glue should be thin enough to flow easily from the brush. While the glue is still soft on the luminous paint, spray the dial with a very thin coat of paint. The paint should be allowed to dry thoroughly before putting into a bowl of water. Soak about fifiteen minutes, then rub off the glue very gently. Do not get the coat of paint too heavy because the water cannot penetrate through the paint to dissolve the glue.

Q. What makes luminous paint more stringy at times than at other times?

A. In assuming that the same amount of thinner or adhesive is used at all times, chilly temperatures and drafts, also old mixture, will cause this stringy condition. The luminous paint flows more smoothly when about body temperature, and fresh. Mix only the amount needed for your immediate use. Do not use radium mixture more than twenty-four hours old.

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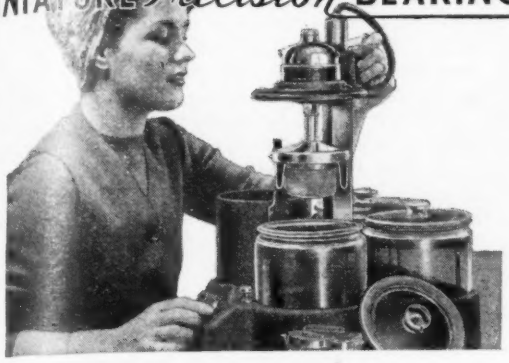

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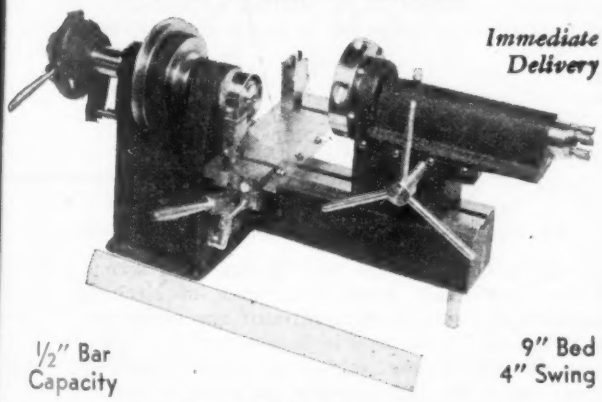

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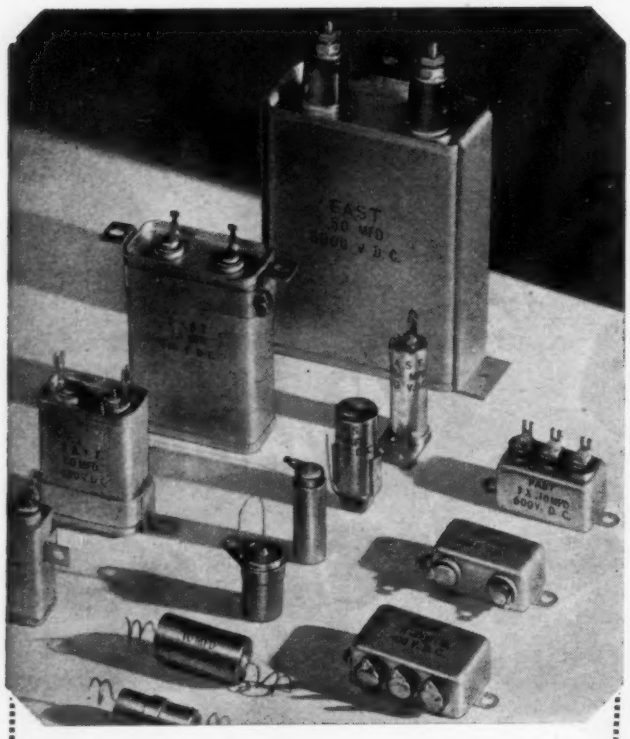

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(Continued from page 344)

tron's action is very similar as that of an ordinary triode with regenerative coupling of input to output circuit and it may be used for similar purposes.

It is possible to use the secondary emission effect and add a normal control grid as well. It may be recalled from Chapter XIII that the plate current of an ordinary screen-grid tetrode reverses at the lower plate voltages, just as does the current represented in Fig. 127. Therefore, by operating the ordinary screen-grid tetrode in the region where the plate current decreases as the plate voltage increases, the Dynatron characteristics may be obtained

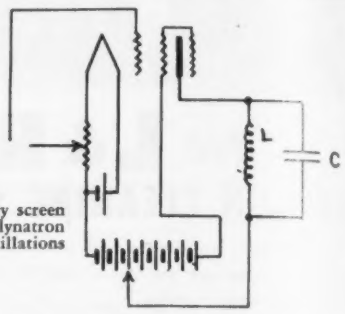

Fig. 128. Here an ordinary screen grid tetrode is used as a dynatron to produce sustained oscillations in L-C circuit.

addition to the action of the normal screen-grid. A connection which accomplishes this is shown in Fig. 128. oscillations are generated in the *L-C* circuit. Such an arrangement produces particularly stable oscillations and is frequently used as a source of known adjustable frequency. Its advantages lie in the fact that the frequency of oscillations in the *L-C* circuit is more independent of changes in tube parameters than in any other simple circuit.

In a more recent development, the principle of secondary emission is used in an ingenuous manner to produce amplification of current to an almost unbelievable degree. This refers to the electron multipliers of P. T. Farnsworth and V. K. Zworykin in their researches in television. The actual methods by which these two investigators achieve their results differ somewhat but in principle the methods are similar. In Fig. 129 consider S to be a source of electrons. These electrons are drawn to a plate P_1 where they cause secondary electrons to be emitted sometimes in the ratio of 8 or 10 to 1 compared to the primary electrons. These

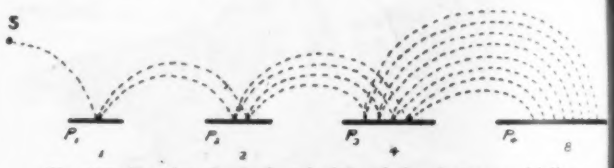

Fig. 129. Showing the basic principle of the electron multiplier.

secondary electrons are then drawn to a second plate p_2 where they again produce a batch of electrons. In the diagram, for simplicity, a ratio of two secondary electrons to one primary electron is shown but even here, with one primary electron starting at S it will be seen that 8 electrons reach the fourth plate. In practice, as many as 10 or 15 stages may be used, producing a current amplification of 10^{10} or more. All these stages are incorporated in a single small tube.

The early multiplier tubes employed a combination of electron-static and magnetic fields to effect the focusing of the electrons but recently tubes using an all-electrostatic focusing structure have been developed.

An electron multiplier of the latter type is shown in Fig. 129. In this tube eleven elements are ingeniously arranged so that primary electrons from the photocathode, together with secondary electrons produced at nine dynodes, travel in a complex circular path to the anode. With this tube a gain of 250,000 is readily obtainable at a total of 1250 volts between the collecting anode and the photocathode. This tube is no longer than an ordinary simple phototube.

These few examples, describing the uses of tubes and principles, are presented not so much to impart information

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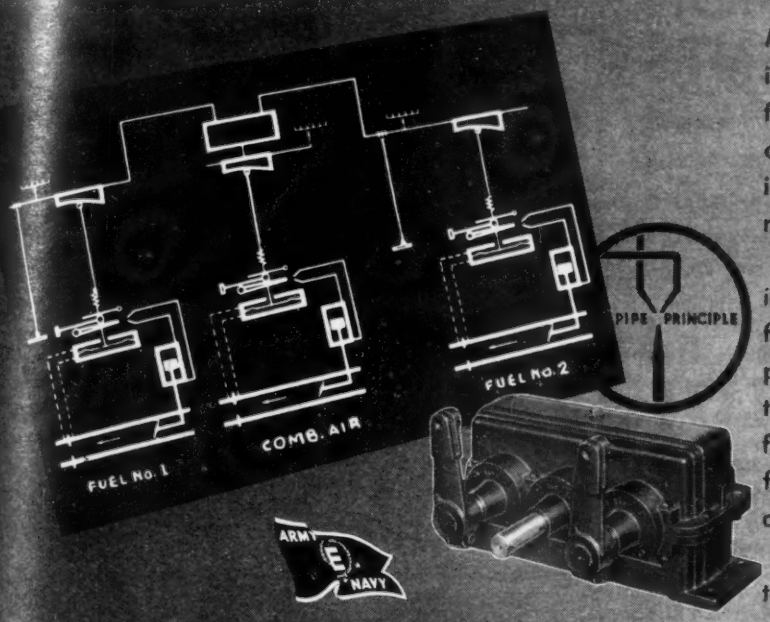

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on the devices and principles themselves but to show the versatility of the electron tube in all its various forms. If, in citing these examples, we seem to have been partial to the communication field, it is only because the communication field was the first to use and develop the electron tube and numerous applications are available to draw from. Principles made use of in the communication field are equally applicable in other fields and a knowledge of them should serve both as a guide and inspiration in adapting the electron tube for use in other fields. The phototube is, of course, the heart of most sound picture systems. It is also general in "facsimile" systems which accomplish picture transmission by wire or wireless.

XX. THE MERCURY-ARC RECTIFIER

With the exception of the photoelectric tubes, all the tubes considered thus far have been of the hot cathode type. There are classes of tubes, however, which do not depend on the use of a hot cathode for a source of electrons; some of these, such as the cold cathode tubes to be described later, are designed for use where extremely small currents are involved while others, those considered in this chapter, are designed for high-current operation.

These high-current tubes are the oldest forms of commercial tubes in existence for they are none other than the well-known mercury-arc rectifiers used in street lighting service long before electron tubes were known in the present sense of the term.

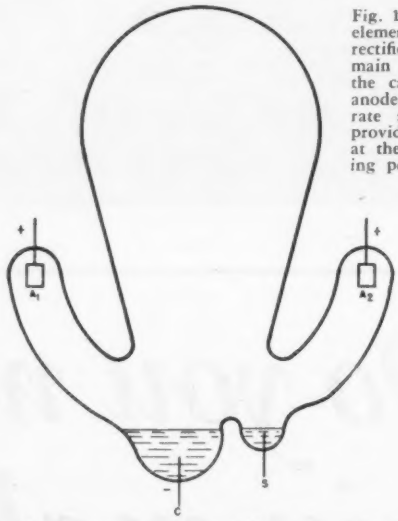

Fig. 130. Section showing the elements of the mercury-arc rectifier. In this tube the main arc is carried between the cathode pool C and the anodes A_1 and A_2. A separate starting electrode S is provided to initiate the arc at the start of each conducting period.

In the mercury-arc rectifier, the source of the electrons is in the so-called cathode spot, formed on the surface of a pool of liquid mercury by the action of the arc. The spot dances about over the surface of the mercury, its size varying with the instantaneous value of the current, but it is always an intense source of electrons.

A typical tube of this kind is shown in Fig. 130. In this case a glass bulb encloses the tube elements, but in large sizes the tubes are made in the form of heavy steel tanks. Referring to Fig. 130, the large bulbous part of the tube is to provide enough condensing surface for the mercury which is vaporized from the pool by the heat of the arc which forms between the cathode pool C and the anodes A_1 or A_2. The anodes, as indicated, are fixed in the arms extending out from the main tube, this arrangement tending to isolate the anodes from each other, thereby reducing the tendency of the current to flow from one anode to the other as a result of continuous ionization.

A rectifier of this kind is not self-starting; some means must be employed to create an initial ionization which initiates the arc. In the tube shown this is accomplished by applying a voltage between the starting electrode S and the cathode C and tilting the tube until the two mercury pools make contact. Then, as the tube is tilted back to its normal position, an arc forms on the surface of the cathode pool C. This arc forms what is known as a cathode spot on the surface of the pool which serves as an intense source

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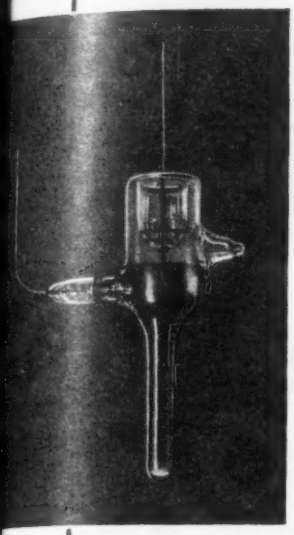

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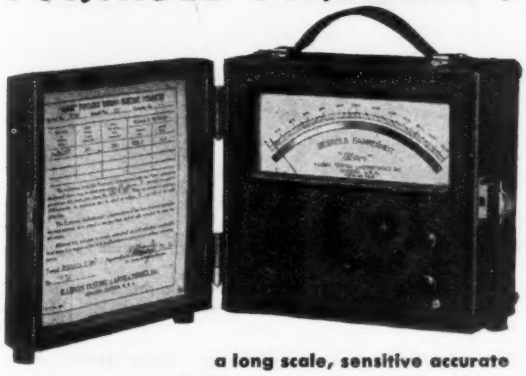

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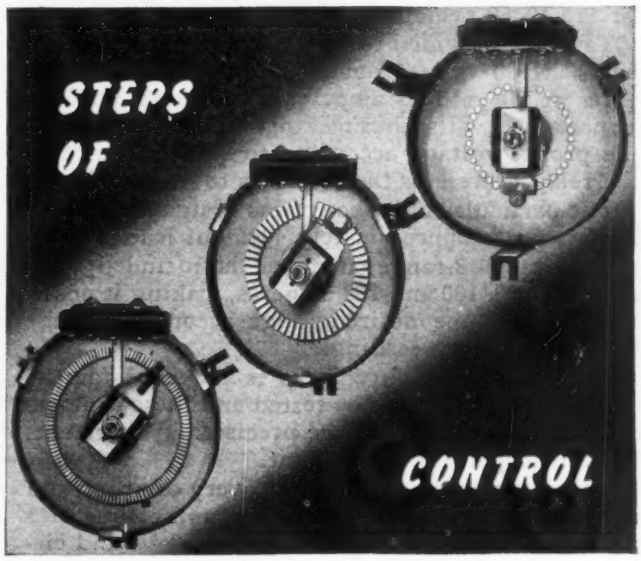

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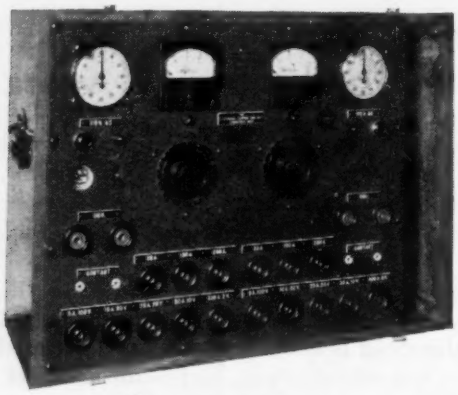

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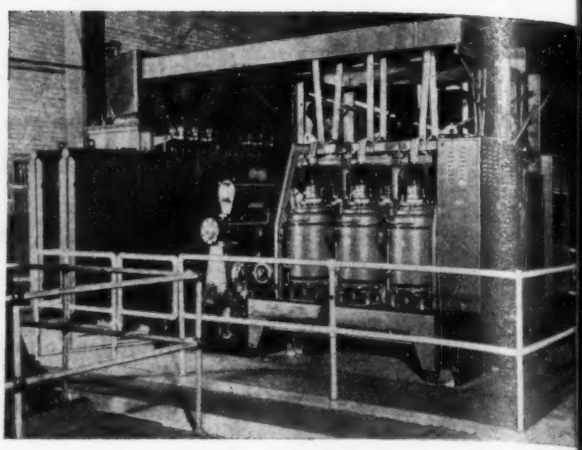

Fig. 131. A large steel tank polyphase mercury arc rectifier. *(Photo courtesy Allis-Chalmers Mfg. Co.)*

of electrons, and if, when this cathode spot has come in existence, potential is applied to the main anodes, A_1 a A_2, the main arc forms between them and the cathode In this way the main arc is initiated. Thereafter the ma arc itself maintains the cathode spot and as long as pote tial is maintained on the anodes the tube remains in conducting state. The tube de-ionizes and becomes no conducting in a few microseconds if the potential on th anodes is removed, however, and for this reason, wit alternating potential applied to the anodes as is always th case in rectifier practice, the tube stops conducting afte the first half-cycle and requires starting again unless b some method the current can be maintained.

In some tubes this is done by providing auxiliary anode which are energized by direct current and thus maintai an arc to the pool continuously. In other cases, as in Fig

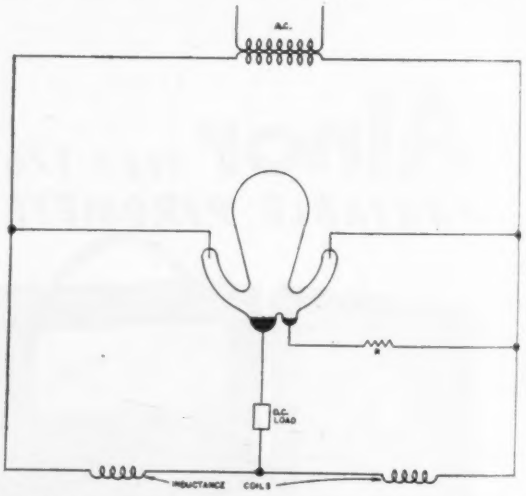

Fig. 132. Mercury arc rectifier showing the use of inductances in the anode circuit to maintain the arc.

132, inductances are added in each anode circuit which cause the current in one anode to continue until the other begins passing current. The theory of the cathode spot in the mercury-arc rectifier has been the subject of much discussion and considerable study but still is not fully understood. Whether the action is thermal or electrostatic or both is not entirely clear but that has made little difference in the development of the principle for commercial use.

With the mercury-arc type of rectifier, the overall size of the tube and its elements determines the ease or difficulty of evacuating the tube and maintaining a permanent vacuum. As the tube becomes larger it becomes increasingly difficult to treat the various parts so as to remove all traces of gas in the metal and glass. If this gas is not removed at the time the tube is constructed it will come

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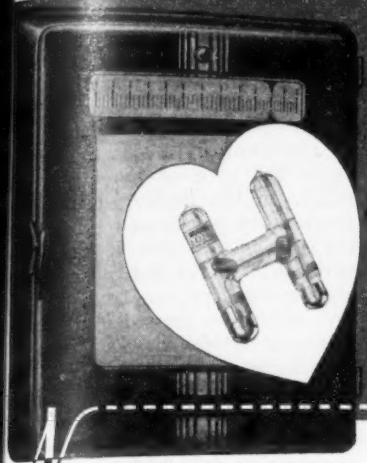

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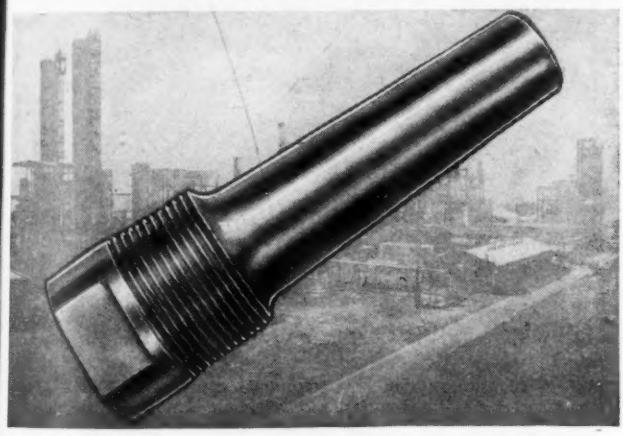

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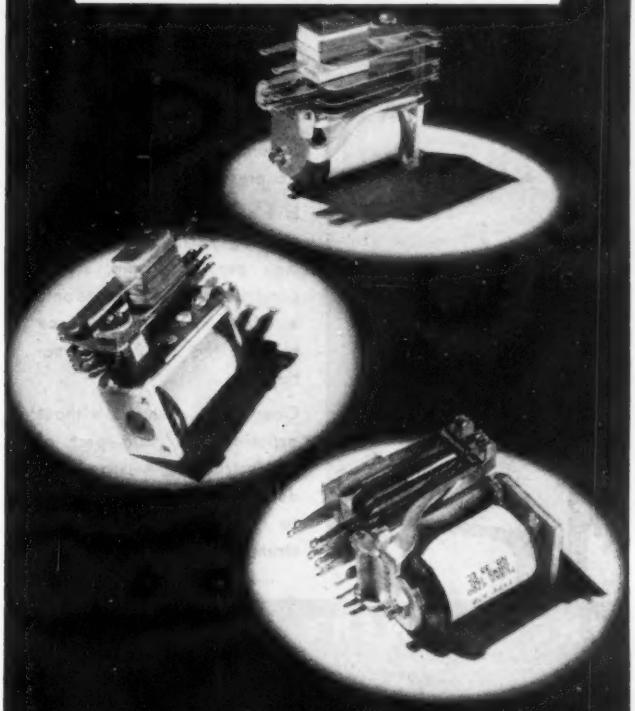

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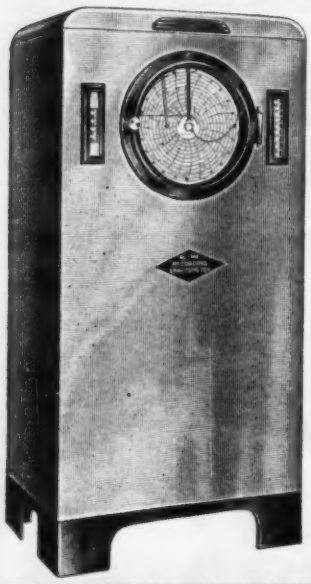

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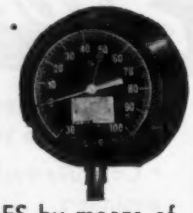

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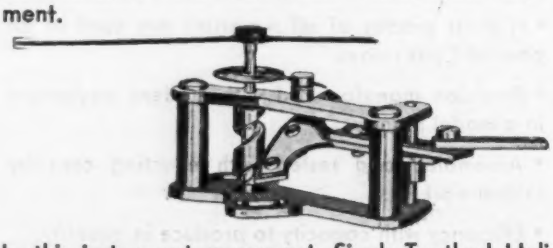

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out gradually while the tube is in service and thereby cause failure.

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For this reason, tubes of high capacities, and rectifiers of this kind made in sizes up to 3000 kw. or more, are usually made with metal tanks in which the vacuum is maintained continuously by a vacuum pumping system. This introduces complexities in construction and operating troubles but in the case of large capacities this is justifiable.

The Grid-controlled Mercury-arc Rectifier

Tubes of this type are fundamentally diodes, and as such are simple rectifiers. As in the case of the hot cathode gas-filled tube, it is possible in the mercury-arc rectifier to add a control grid between the anode and the cathode. The action of the control grid in this case is exactly the same as that of the control grid in the hot-cathode triode or thyratron; it can only prevent the arc from starting; it cannot stop a discharge which has started. As described in the articles on the gaseous triode, as soon as a discharge is started there are approximately equal quantities of electrons and positive ions in the gas space between the anode and cathode. Since the ions neutralize the electrons, there is no space charge when the discharge has started and there can be no appreciable grid-control effect. The only way to stop the discharge is to reduce the current to

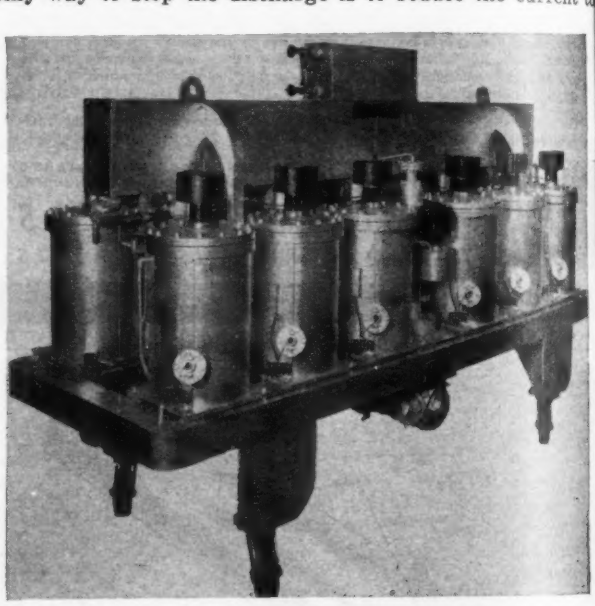

Fig. 133. A modern ignitron type grid-controlled mercury arc rectifier.
(Photo courtesy Westinghouse E. & M. Co.)

zero by opening the circuit or by reducing the circuit voltage. In an a-c. circuit where the voltage passes through zero twice each cycle, the grid can regain control at these times.

The manner of mounting the control grids in a grid-controlled mercury-arc rectifier and the design of the grids are of course quite different from the grid mounting and design in the hot-cathode gaseous tricde, mostly because of the high capacities in which these rectifiers are made—but their function is fundamentally the same. The unit shown in Fig. 133 is a high-power grid-controlled rectifier of this type, complete with its vacuum pumping equipment.

The addition of electrically-energized grids has greatly extended the use of the mercury-arc rectifier since these grids make possible voltage control under load and operation of the unit as a rectifier or an inverter* of power.

The Igniter Tube

During the past few years, however, a new form of mercury-arc rectifier has been developed which, already, has received extensive application, especially in the control of electric arc welding. This is the igniter type of tube,

*An inverter is the opposite of a rectifier, it converts alternating current into direct current.

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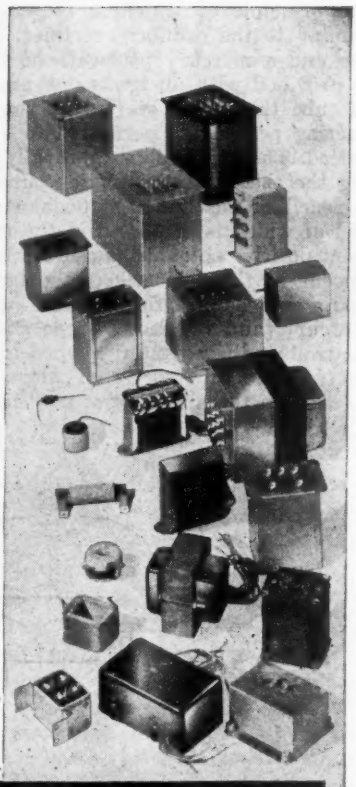

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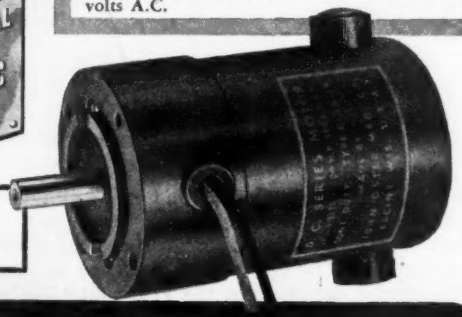

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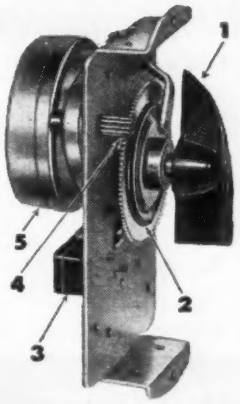

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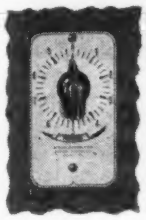

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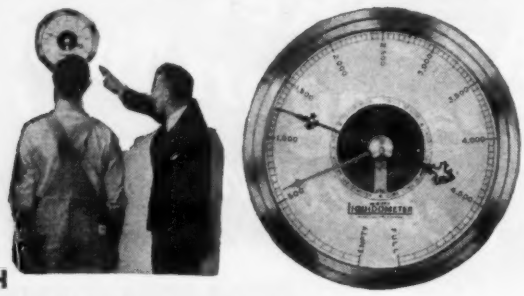

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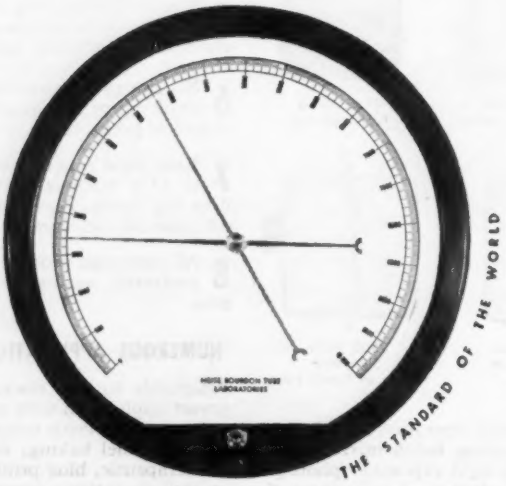

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the principle of which is shown in Fig. 134. It is very similar to the ordinary rectifier, having an anode at the top and a mercury pool cathode below, but in addition it is provided with an igniter or arc starter. With this type of tube the arc is started at the beginning of each conducting period and permitted to go out at the end of this period. There is still no generally accepted theory regarding the theory of the igniter but it consists essentially of a pencil or resistance material such as carborundum, the end of which is immersed in the mercury pool. When sufficient positive potential is applied to the igniter, tiny sparks appear at the point where the igniter enters the mercury and a cathode spot forms at the junction of the igniter and mercury, and the main anode starts to pass current. By controlling the potential applied to the igniter it is possible to turn the tube on or off when an alternating potential is used on the anode, or it may be started at any point in

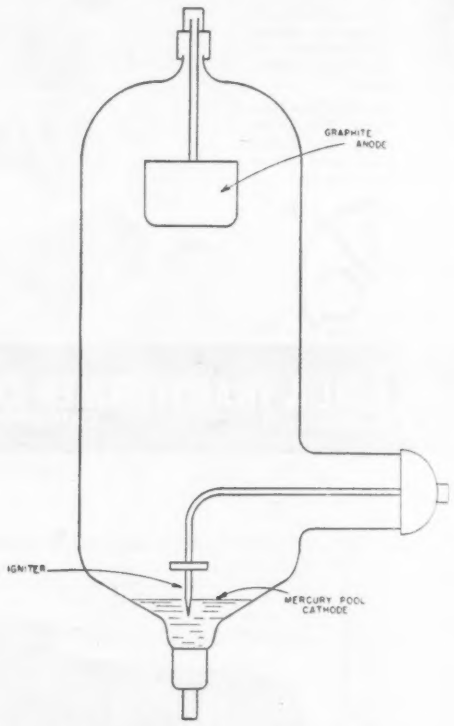

Fig. 134. The igniter type of mercury arc rectifier.

the cycle. Thus, by controlling the voltage on the igniter in this type of tube, the same results may be obtained as when the voltage on the grid of a grid-controlled rectifier is controlled. The igniter type of tube is, however, a much more simple device than the grid-controlled rectifier.

As mentioned above, the theory upon which the igniter operates is subject to some difference of opinion. Slepian and Ludwig of Westinghouse who were primarily responsible for its development regard* the action to be the consequence of a high potential gradient at the junction of the rod and the mercury, and have advanced mathematical as well as physical evidence that such high potential gradients as are necessary can be made to exist. Others admit that though the theory of Slepian and Ludwig may be applicable to certain limiting conditions, it needs modification to apply to practical cases. According to certain of the General Electric Co. engineers, ignition in these tubes is caused by the current flowing in a narrow band of particles on the igniter surface at the meniscus of the mercury.† While investigating the effects of surface (of the igniter) conditions on starting characteristics, it was found that dull matte surfaces required lower starting current than did shiny surfaces, even though the material was identical in the two cases. When the mercury could be made to wet the

*A New Method of Starting an Arc. *Electrical Engineering*, September, 1933, page 605.

†Theory of the Immersion Mercury-Arc Igniter. *General Electric Review*, October 1935, page 464.

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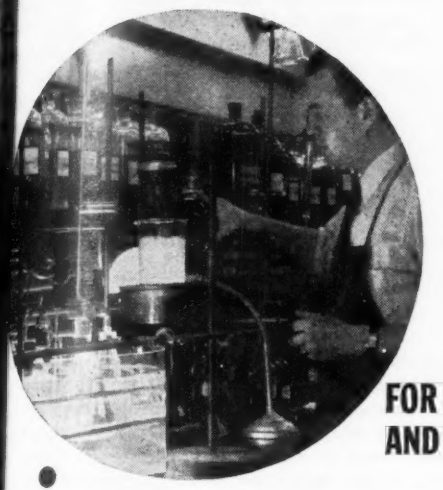

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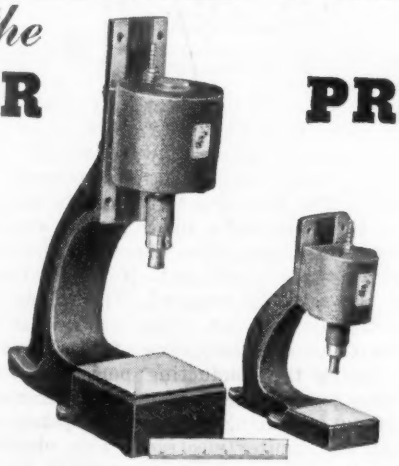

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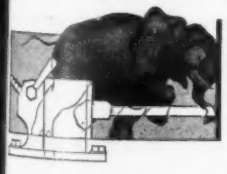

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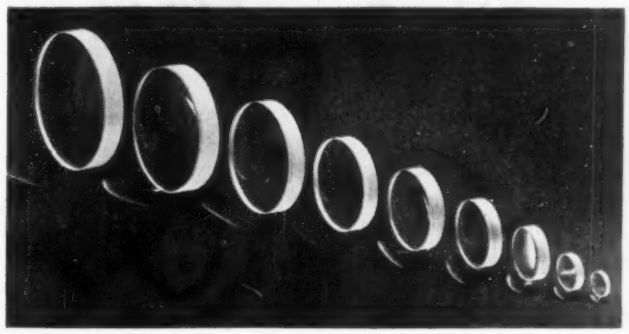

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igniter material, larger starting currents were required. It appeared probable from these experiments that low-current starting depends upon having as poor a contact as possible between the mercury and the igniter material. Putting it another way, the surface of the igniter should consist of many fine particles which make contact with the mercury only through their edges and points.

Regardless, however, of the exact principle upon which the igniter operates, the tube today is an established success and its use is growing daily. The simplicity of its construction lends it to many applications where the ordinary grid-controlled mercury-arc rectifier would be too cumbersome, and the rapidity of its action has extended the scope of electric welding to a remarkable degree. In certain electric welding operations it is necessary to pass heavy currents for very brief periods of time and under controlled conditions. The igniter tube provides this control and for short intervals of time is capable of carrying relatively enormous currents.

In high-speed spot welding a current of several thousand amperes is sometimes required for a time as short as one half cycle. No mechanical contactor could furnish such close control for such high currents but the igniter type of mercury arc tube meets these requirements very effectively.

Aside from its obvious advantages as a rectifier, the igniter tube has many applications such as motor speed control, theatre light dimming, voltage regulation, etc.

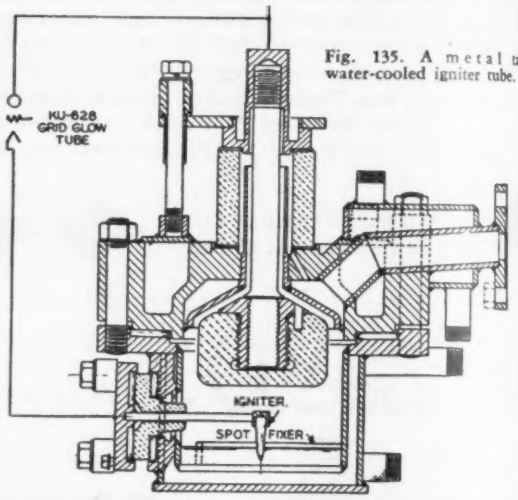

Fig. 135. A metal tank water-cooled igniter tube.

While the glass-walled tubes are capable of carrying momentary currents of a thousand amperes or more, for heavy-duty continuous service, water-cooled steel-tank igniter tubes have been developed. A cross-section of such a unit is shown in Fig. 135. This tube consists of a mercury pool cathode at the bottom of a small tank of simple design, a graphite anode insulated from the tank and an igniter electrode which is also insulated. No insulation of the cathode from the tank is required. The anode is spaced close to the cathode and no grids or shields intervene between the two. As a consequence of this close spacing the arc drop during the conducting period is low, and at the onset of this period, the tube quickly becomes highly conducting without requiring any special system of excitation other than the igniter electrode. This electrode is of silicon carbide. Its lower end is immersed in the mercury and the upper end is welded into the holder. When current of a few amperes is caused to flow through the rod in the direction of holder to mercury, a cathode spot forms on the mercury in a few millionths of a second and the arc starts. The action, of course, is exactly the same as in the case of the glass tube but, because of the close spacing of the elements, a higher efficiency is realized.

From the foregoing it is evident that insofar as the function of the igniter tube is concerned, it is essentially the same as that of the grid-controlled mercury-arc rectifier but there is a fundamental difference between the control action in a thyratron or grid pool tube and the action of the igniter rod in an ignitron. In thyratrons and grid pool tubes, the grid *prevents* the formation of an arc,

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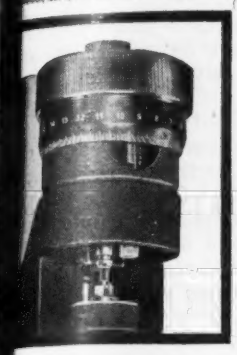

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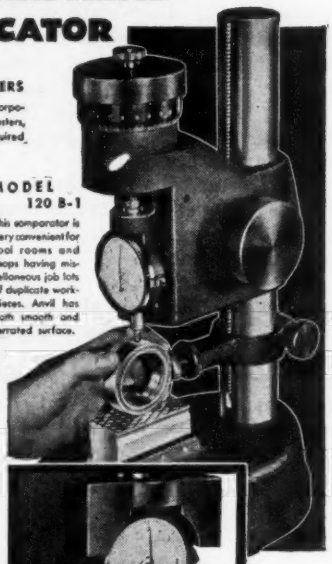

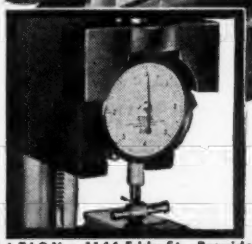

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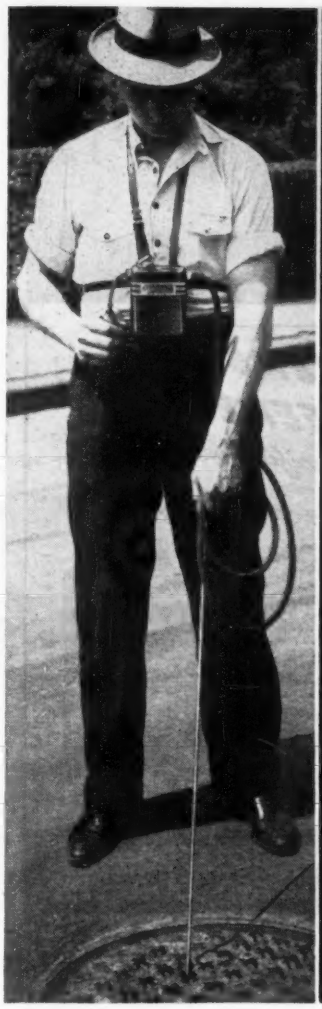

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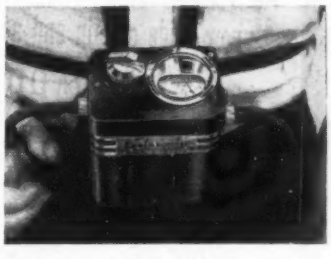

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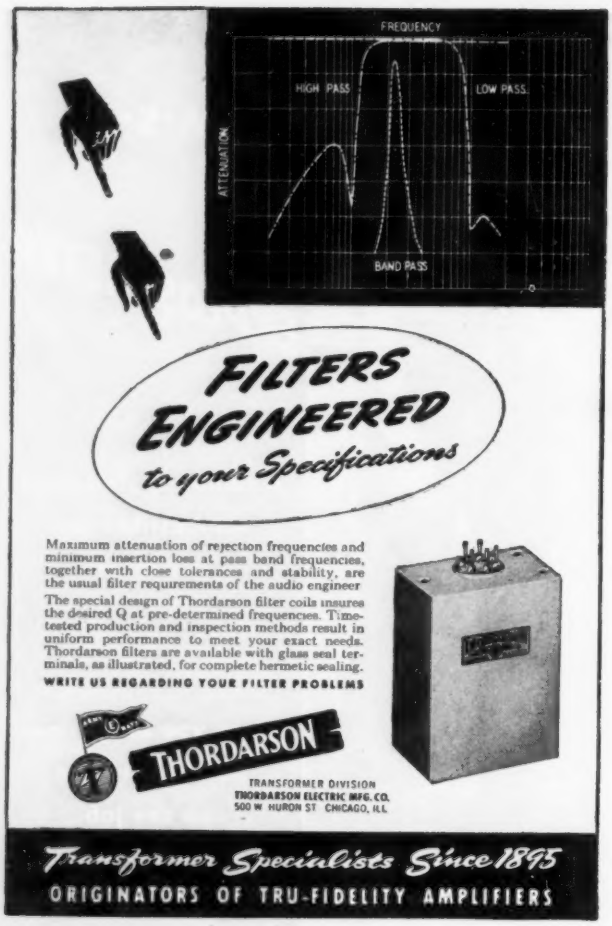
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whereas the igniter *initiates* the arc. In the grid-controll tube the electrons already exist in the tube (because of t presence of an externally-heated cathode or of an arc the keep-alive electrode), but the grid electrostatically p vents them from reaching the anode until a critical volta is reached. In the ignitron, on the other hand, the tube in a non-conducting state until the igniter circuit is en gized when conduction is forced. By reason of these diff ences, the control of an ignitron is somewhat more relia than that of other units. The igniter electrode in no w hinders the conduction of the arc after it has form whereas the grid often does so and adds about two vo to the arc drop.

The igniter tube is probably capable of considerable f ther development but in the comparatively short time sin it made its appearance it has received considerable co mercial application.

The development of the igniter type of tube is st another example of what a more intimate knowledge of el tronics is doing to the field of electrical engineering general. It vastly extends the scope of a device (the me cury-arc rectifier) which before could fulfil only one fu tion. Today mercury-arc tubes serve not only as rectifie but also as inverters and control devices for the cont of current and frequency in electric circuits.

To be continu

ELECTRIC GAGING METHODS

Continued from page 339

employed, μ the permeability of the core material, A t cross-sectional area of the core, d the length of the ma netic path, and L the inductance in henries.

If an air-gap is introduced, the effect is as though t length of the magnetic path were increased by an amou equal to the product of the length of the air-gap and t permeability of the magnetic material.

If the air-gap is large, its effect becomes more pr nounced than the effect of the iron core, and the formul just given reduces to this:

$$L = (3.2 \times A \times N^2)/(a \times 10^8)$$

in which the symbols have the same meaning as previously and a signifies the actual air-gap plus the air-gap equiva lent of the iron core.

These formulae for computing inductance apply only t coils having a large portion of the magnetic circuit com posed of iron or other highly-permeable material; for ai core coils other formulae must be used. For the pick-up in which a moving soft-iron armature composes only small proportion of the total length of the magnetic circui while the rest is air (the movement gages of Figs. 34 and C, for example) these formulae are of little valu Most such gages are designed on a basis of experienc and a few rough empirical generalizations.

The magnetic permeability of the grades of iron cu tomarily used in these gaging elements varies from abou 1,000 at low flux densities to about 2,500 at higher flu densities. This is the a-c, permeability, or incremental per meability; it is the proper value to use in such computa tions, since alternating current only flows through th gaging element.

Considering a permeability of 1,000 it is apparent tha an air-gap of 0.001″ will increase the reluctance of th magnetic circuit about as much as would an increase i the iron core length of 1″. Thus, for a strain gage lik that of Fig. 34 A, which has a core length of about 1.5 and which is used normally with an air-gap of 0.008″ t 0.010″, the air-gap has a reluctance about six times as great as that of the iron core. If the air-gap is change by 10 per cent, the inductance of the unit will be change by nearly 9 per cent.

The ohmic resistance of most magnetic gaging element is only a few ohms, and the resistance of the leads is often comparable. Since the measurements are made in terms of variation in impedance, it is desirable to maintain the ohmic resistance (which does not vary with the magnitude being

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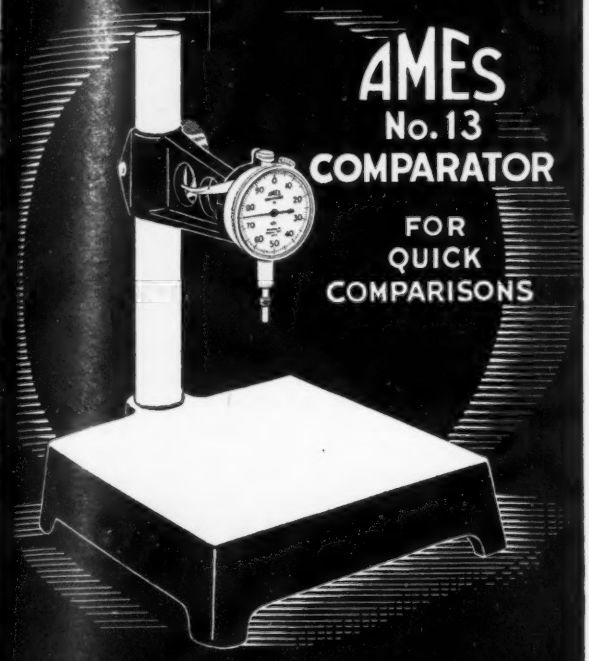

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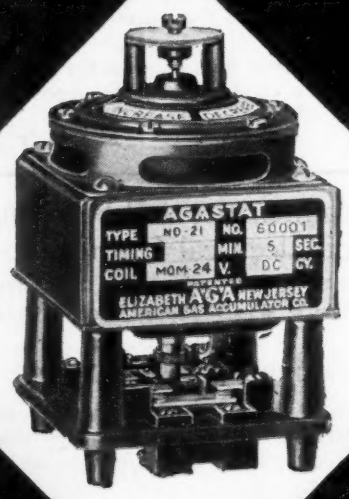

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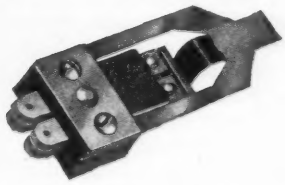

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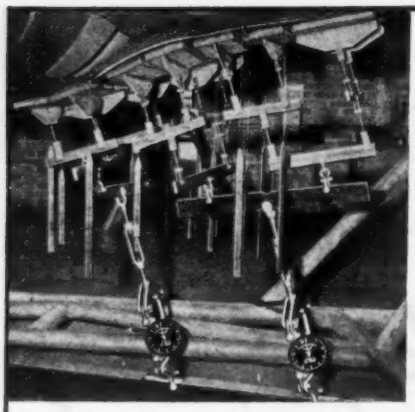

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measured) low compared to the reactance of the circuit. The inductive reactance may be increased by increasing the inductance, or by increasing the frequency of the exciting current. It is desirable to employ 60-cycle excitation whenever possible, because of its convenience. For rapidly-changing phenomena, the excitation frequency must be several times as high as the highest frequency being recorded. The higher frequencies of excitation make possible the reduction of mechanical size of the gaging element without losing too much sensitivity.

Mutual inductance (defined above) is a property of coupled circuits which controls the transfer of energy between them; thus the current (or voltage) output from a variable-air-gap transformer is proportional to the mutual inductance of the coils of that transformer. The coupling between two circuits is never perfect; the ratio of the maximum possible mutual inductance to the actual mutual inductance is called the coefficient of coupling. It is described mathematically thus:

$$k = M/(L_1L_2)^{1/2}$$

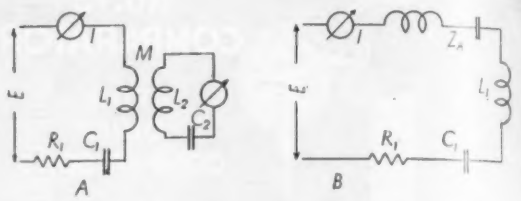
In this relation k indicates the coupling coefficient, M the "perfect" mutual inductance, and L_1 and L_2 the self-inductances of the two coils.

In iron-core transformers designed for the transfer of power, the coefficient of coupling is nearly unity; in magnetic gaging elements containing an air-gap, it is much lower. For this reason, the voltage ratio of a variable-air-gap transformer is not equal to the turns ratio, and so the output voltage is an indication of the length of the air-gap.

The difference between the maximum possible mutual inductance and the actual mutual inductance is a measure of the leakage inductance, or of the amount of the magnetic flux from one coil which does not pass through the other coil. Any other coil, or conducting material, which intersects this leakage flux will affect the inductance of the coils.

The admittance of a circuit of this type (the reciprocal of its impedance) is in general a criterion of the inductance of the primary coil; this occurs because the inductive reactance is in general high compared to both the ohmic resistance and the capacitative reactance shunting the rest of the circuit. Therefore, any change in the exciting current of the circuit is an indication of such change in the inductance of the gaging element, or of the mutual inductance. This is easily demonstrated.

If two circuits, each containing resistance, inductance and capacitance are set up and inductively coupled together (see drawing) then the current flowing in the primary



circuit will be equal to the quotient of the applied voltage and the total impedance of the circuit, including the reflected impedance of the inductively coupled secondary. In the drawings, L_1 and L_2 refer to the inductances in the primary and secondary circuits respectively, R_1 and R_2 the resistance, C_1 and C_2 the capacitance, and I_1 and I_2 the currents flowing. The mutual inductance of the two circuits is represented by M.

Measurements and analysis of such circuits have demonstrated that the primary circuit behaves just as though the secondary circuit were removed and a new impedance Z_s were introduced in the primary circuit, as in B of the drawing. The magnitude of Z_s is given by this relation

$$Z_s = [M^2(2\pi f)^2]/Z_2$$

in which Z_2 is the impedance of the secondary circuit considered separately and the other terms have been defined above.

From this it is clear that the reflected impedance varies as the square of the mutual inductance, and inversely as the impedance of the secondary circuit. If either of these factors is held constant, a change in the other will affect the admittance of the primary circuit in a predictable manner.

The principle of magnetic induction was stated by Faraday in this manner: when the total magnetic induction linked with a circuit changes, an electromotive force acts around the circuit, the direction of the electromotive force depending on the sign of the change of magnetic induction.

Lenz's law states that when a conductor moves with respect to a magnetic field the currents induced in the conductor are in such a direction that the reaction between them and the magnetic field opposes the motion. Eddy currents induced in a conductor act to oppose the motion of that conductor.

To be continued

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ELECTRONIC REGULATION of Industrial Processes

Concluded from page 330

lation permitted, other types of regulators can be considered. Under these conditions other factors such as maintenance, simplicity, and cost may become the dominating factors. Even under these conditions present-day electronic regulators are not ruled out but the mechanical and magnetic regulators have more of a chance to compete.

Some of the more interesting applications of electronics in industrial regulators may be mentioned briefly. The tin flow temperature regulator, one of the most interesting, has already been described.

A Westinghouse electronic motor control, the Mot-O-trol unit, is also of considerable interest. It provides for accelerating, retarding, reversing, stopping and starting a d-c. motor with smooth speed control over a 40-to-1 speed range and flat speed load characteristics up to 200% load at any speed in this range. These characteristics are obtained by electronic regulating systems which provide for current limitation, *IR* drop compensation, and speed control. Dynamic braking is provided for stopping and regeneration for reversal. In addition, the flexibility of the electronic control makes it very simple to include the Mot-O-trol unit in any automatic system.

Loop regulators are also of interest. They control the unreeling of strip by holding constant the depth of a small loop. If the loop tends to shorten, the speed of unreeling increases. If the loop tends to deepen, the speed of unreeling is decreased. By this means sudden jerks which might break the strip are eliminated.

CONCLUSION

In summarizing I should like to mention again:

I. The six basic functions performed by electronic tubes:
   1. Rectification.
   2. Amplification.
   3. Generation.
   4. Control.
   5. Light to electricity.
   6. Electricity to light.

II. The three fundamental features of regulating systems:
   1. Comparison standard or standards.
   2. Feedback initiated by deviations from the standard, to eliminate the deviations.
   3. Regulations systems are oscillators.

III. The basic limitation of the oscillating or astatic regulator:
   1. Speed of correction is a compromise between amplitude of transient swings and amplitude of oscillation.
   2. Applications are best made where transients are not important.

IV. Methods of changing astatic regulators to static:
   1. Correction must be made proportional to deviation.
   2. Dead zone operation.
   3. Anti-hunt.
   4. Anticipation.

V. Advantages of electronic regulators:
   1. Short delays.
   2. High rate of correction.
   3. Flexibility and wide range.

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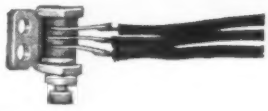

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CORBIN
TACHOMETERS

FUEL INSTRUMENTATION

Concluded from page 327

iron ore reduction and oxidation process to furnish the necessary hydrogen. Proper temperature ratio and pressure controls save time and make for economical operation. Controlled gas-fired units are also used for drying blood and tankage. Dried blood is a source of albumen and is also used in glues and in retarders.

Textiles: The textile industry requires positive controls in the manufacture of glass wool and of rock wool fibres. Singeing of cotton and wool fibres by passing them through controlled flames at high speed involves proper gas-air radio control to produce the necessary flame. In the dyeing and drying of cloth, processed steam, oftentimes generated in gas-fired boilers, is economically employed.

Synthetic Rubber: Various controls are applied in the manufacture of synthetic rubber from hydrocarbons and other materials. Inert gas atmospheres are employed to furnish a protective blanket for stored hydrocarbons which are later polymerized to form a latex for Buna S rubber.

Cylinder Gases: Various gases are served to the trade in high-pressure cylinders. These gases include acetylene for welding, carbon dioxide, propane and butane in bottled gas systems, and oxygen, nitrogen, ethylene, nitrous oxide, etc., and all are fitted with regulators to properly control the flow. Ratio controls are also employed in many instances.

The mention of gas welding alone allows the imagination to visualize the saving in man-hours in comparison with other methods of construction and repair.

The use of liquid carbon dioxide as a fire extinguisher has increased tremendously during the past few years. It has been used with great success in airplane fires and in other fires not easily quenched with water, such as flammable liquids and electric fires. Carbon dioxide systems are often installed for fire protection in manufacturing plants for cases of emergency. All such systems are fitted with regulating controls.

Automatic Space Heating: Heating industrial, commercial, and residential buildings by gas conserves many man-hours, and in many instances eliminates janitor service. Either central or individual heaters may be employed. At the present time floor and panel heating are gaining in popularity by reason of the uniform distribution of heat.

Gas Ranges: Restaurant and domestic gas ranges, properly equipped with controls (especially those that are known as "CP" or Certified Performance ranges) save fuel and help prevent spoilage of food by improper cooking.

Gas-fired Steam Boilers and Automatic Water Heaters: In addition to the use of gas as a fuel for boilers in industrial plants, and often in electric

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erating stations (usually operated the interruptible rate and on natu- gas), many small gas-fired boilers employed. These are automatically ipped, and they furnish steam as uired.

Both industrial and domestic water ting may be done by automatically- trolled heaters.

Coke as Fuel: Coke is the important l in the manufacture of metallurgi- products — especially of iron and el. Steel company coke oven plants equipped with the proper instru- nts for temperature, pressure, ratio, d other controls, including propor- ners, and operate to produce the d of metallurgical coke desired rough the blending of certain coals.

Utility companies oftentimes have -product ovens for the production of s with coke as the by-product. Such ke is a most valuable fuel and lends lf to labor-saving and economical eration when burned in furnaces uipped with proper draft and tem- rature controls. This is especially e in stoker-fired furnaces.

Coke breeze is a valuable boiler fuel d is used as such in a number of ants.

Stokers for firing domestic coke have en on the market for a number of ars. These sometimes operate so that en the ashes are automatically re- oved from the ash pit. Some coal okers are also thus fitted.

Oil as Fuel: Oils of various grades nd themselves to furnace controls, nd either gas or electric pilot lights e employed in connection with these ntrols. Many industrial plants have mbination gas-oil burners on an in- rruptible gas rate, and can switch om gas to oil on short notice.

Laboratory Control: Chemical and hysical laboratories are equipped with pparatus to continuously check plant oducts. Many automatic devices are mployed to further this. Calorimeters, ecording thermometers and gages are ndispensable aids in this connection. n the testing of products, automatic ampling is in operation in many lants.

Establishments which are not satis- actorily equipped with instruments hould carefully consider the savings hat would accrue through their use. s improvements take place in instru- entation, as, for example, new devel- pments in electronic controls, opera- ors might find it profitable to replace ld models with new, improved designs.

In closing, it should be pointed out hat the proper maintenance of all in- truments mentioned herein is of ut- ost importance, and constant vigi- ance must be exercised to achieve best esults with these important tools. The hemist, the physicist and the engineer lay a leading role in this connection.

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Instrument Societies

CHICAGO

The April meeting was held on Monday evening the 3rd, in the Merchants & Manufacturers Club. Speaker of the evening was Dr. W. N. Greer of Leeds & Northrup Co. whose subject was "pH Control." Our speaker gave an unusually instructive talk based on the many years of experience which he has had with this particular subject.

Marking the close of the most successful year since the inception of our society, the May meeting was held on Monday evening the 1st, at the Merchants & Manufacturers Club. Those present had the privilege of hearing what was perhaps the most enjoyable talk in the history of our meetings: "Electrical Recording Instruments" by Mr. R. J. Kryter of Esterline-Angus Co.

The new slate of officers for the next term was announced and is headed by the new president, Mr. Hugh Ferguson.

—J. A. Riggs

Northern Indiana Society for Measurement and Control

EDUCATION — FRATERNITY — DEMOCRACY

The May meeting of the N.I.S.M.C. was held Friday, the 12th, at the Lake Hotel in Gary, Indiana.

The speaker for the evening was Mr. Gordon R. Thomason, of the Mason-Neilan Regulator Company, who spoke on "Pressure Reducing and Regulating Valves." The talk was very instructive and received with intense interest. A copy of this talk will be sent to the members at a later date.

The N.I.S.M.&C. held its election of officers for the coming year of 1944-45. After the tabulation of ballots the new officers are:

Ray W. Schreiner, Continental Foundry & Mach. Co., *President.*

Henry F. Wagner, Gary Sheet Mill, *Vice-President.*

Thomas Stafford, American Steel Foundries, *Recording Secretary.*

Kenneth M. Frame, Standard Oil Co., *Corresponding Secretary.*

Ralph Mayer, Socony-Vacuum Oil Co., *Treasurer.*

These men will take over their office at the September Meeting. A standing vote of thanks was given the Officers of 1943-44 for the successful year they have given the society.

—Kenneth M. Frame

Past President V. H. Hiermeir of the N.I.S.M.C., who for four years had been Brown Instrument's Industrial Service Manager in the Chicago Office, has just been transferred to St. Louis as Industrial Manager, which is a promotion. He writes: "I regret very much leaving the Calumet industrial area—Chicago, Whiting, Gary, and Hammond—where I resided for twenty years and made sincere friends. I had been teaching for the War Training Program under the supervision of Purdue University and have had to give that up. I had also been setting up a permanent industrial instrument training school, as part of a permanent Technical Institute supplying off-campus training at college level, by Purdue University. I sincerely regret my inability to continue with this work. My new office address will be 4030 Chouteau Avenue, St. Louis."

NEW YORK

At the May 31st meeting of the N.Y.-S.M.C. Mr. C. H. Backman of the General Electric Company gave a very interesti lecture on the General Electric Electr Microscope. The internal construction a operation of the microscope was discuss in detail. The speaker gave a review of t development of the instrument from t early foreign and American makes up the latest war model. The talk was illu trated throughout with slides from t speaker's collection. During the discussi period many questions were expertly a swered by Dr. Backman.

—H. R. Kalbfleisc

PHILADELPHIA

The speaker at the May 17th meeting the Philadelphia Society for Instrument tion was Mr. L. K. Spink of the Foxbo Company, who gave a very helpful a instructive talk on "Installation and Ope ation of Differential Flow Meters." M Spink pointed out that one outstanding a vantage of the differential type meter w its ability to reproduce results accurate even though the actual reading might b in error. This characteristic is particular valuable in control applications or co tinuous processes. He also presented highly interesting series of curves showin the magnitudes of the errors which can b expected in flow measurements by differe tial meters from such factors as size pressure tap connections, edge thickness the orifice, rounding the upstream edge the orifice, pressure tap spacing, inside pi diameter, viscosity of the flowing fluid an Reynolds' number.

Attendance at the dinner was 30, an at the meeting 65.

—J. E. Gambril

INSTRUMENT SOCIETIES CALENDAR

City, Society and Secretary			Date	Place	Subject	Speaker
Atlanta	Georgia Society for Measurement & Control	Roger W. Allen, 376 Nelson St., S.W., Atlanta				
Baltimore	Baltimore Industrial Instrumentation Society	C. B. Willnecker, 6732 Danville Ave., Dundalk, Md.				
Chicago	Chicago Society for Measurement & Control	A. J. Butler, 2626 W. 31st Blvd., Chicago				
Cleveland	Cleveland Instrumentation Society	F. G. Meulenberg, DuPont Exp'l Lab.				
Gulf Coast	Gulf Coast Instrument Maintenance Men's Ass'n	T. H. Pierson, 3030 Roberts St., Beaumont, Tex.				
Hartford	Hartford Society for Measurement & Control	Stephen J. Zelle, Whitney Chain & Mfg. Co., Hartford, Conn.				
Kansas City	KC Industrial Instrumentation Society	Gordon H. Burke, Burke Engineering Co.				
Newark	New Jersey Society for Measurement & Control	Robert H. Gray, 84 Centennial Ave., Cranford, N. J.	June 6(B)	Essex House	Electronic Pyrometry	C. O. Fairchild, C. J. Tagliabue Mfg. Co.
New York	New York Society for Measurement & Control	H. R. Kalbfleisch, 114-35 No. Blvd., Flushing, N. Y.	June 27(B)	Building Trades Emp. Ass'n, 2 Park Ave.	Petroleum Refinery Instr. Maintenance	M. H. White, Atlantic Refining Co.
N. Indiana	Northern Indiana Soc. Measurement & Control	R. W. Schreiner, 4 Waltham St. Calumet City, Illinois				
Philadelphia	Philadelphia Society for Instrumentation	J. E. Gambrill, 1317 Spruce St.	Sept. 20(B)	Engineers Club	To be announced	To be announced
Pittsburgh	American Society for Measurement & Control	L. M. Susany, c/o Carnegie Institute, 4400 Forbes St., Pgh.	Sept. 25(B)	Roosevelt Hotel	Instruments and Synthetic Rubber	J. G. Kirkpatrick, Koppers United Co.
St. Louis	St. Louis Society for Instrumentation	Gus Holubeck, Union Electric Co., Venice, Ill.				
Toronto	Canadian Society for Measurement & Control	T. C. Agnew, Minneapolis-Honeywell Reg. Co., Toronto				
Washington	Instruments Society of Washington	R. C. Darnell, 2400 "S" St. SE, Wash'n				

(A)Meeting at 7:30, no dinner. (B)Dinner at 6:30, meeting at 8. (C) Dinner at 7, meeting at 8. (D)Meeting at 8, no dinner.

Let's Have News Anyway!

In spite of no meetings in summer, keep your Society in print! Secretaries and Publicity Chairmen (and others) please send me items—even "personals"—to run on this page—which belongs to you.

—M. F. Behar, *Editor*

Tougher

POWER RESISTORS

★ Greenohms — those green-colored inorganic-cement-coated power resistors now found in so many radio and electronic assemblies — can take an awful beating. Even when seriously overloaded—sizzling hot—they don't burn out, flake, peel, crack. 10 and 20 watts fixed; adjustable, up to 200 watts. Choice of mountings, terminals, taps. And remember, only Clarostat makes Greenohms.

★ Write for Literature . . .

Sent on request. Also let us quote on your power resistor or other resistance and control requirements.

CLAROSTAT Controls and Resistors

CLAROSTAT MFG. CO., Inc. · 285-7 N. 6th St., Brooklyn, N.Y.

There's **NO SUBSTITUTE** for

The "Know How" in OPTICS

Tinsley Laboratories' long EXPERIENCE in Precision Optics and Instrument manufacture—

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—are a guarantee that your requirements for

LENSES
PRISMS
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will be competently and reliably executed!

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Time Switches

Relays

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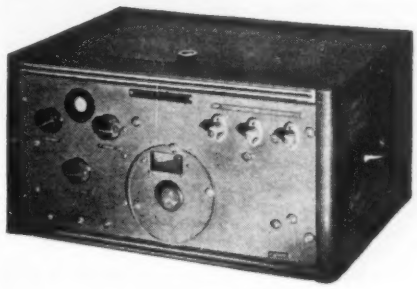
AUTOMATIC ELECTRIC MANUFACTURING CO.
MANKATO, MINNESOTA

RF CAPACITOMETER



DESIGNED for precision measurements of small capacitance and inductance, the G-E radio frequency capacitometer has found acceptance in colleges and industrial laboratories due to its simplicity and compactness.

Other units in the new General Electric line of ELECTRONIC MEASURING EQUIPMENT include: G-E power supplies, wave meters, wide band oscilloscopes, square wave generators, signal generators and various other instruments in the ultra-high frequency and micro-wave fields for measuring electronic circuits and checking component parts.

• *For complete details, please mail coupon below. We invite your inquiry for G-E electronic measuring equipment made to meet your specific requirements.*

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ELECTRONICS DEPARTMENT
General Electric Co.
Schenectady, N. Y.

Please send, without obligation to me, the General Electric Measuring Instrument Catalog, I-6 (loose-leaf), for my information and files.

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GENERAL ELECTRIC 184-C4
Electronic Measuring Instruments

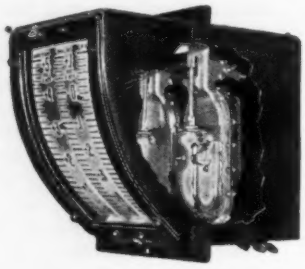
BAILEY METERS

METERS and CONTROL *for Boiler Room Service . . .*

Boiler Meters Reduce fuel costs, lessen maintenance and outage, lower standby costs, and add capacity. They indicate, record and integrate Steam Flow from the boiler, record Air Flow supplied for combustion and record Flue Gas Temperature.

Bailey Boiler Meter

Multi-Pointer Gages for indicating drafts, pressures, differentials are available with any number of pointers from one to twelve. They are actuated by sturdy yet sensitive diaphragm units.



Multi-Pointer Gage

Flow Meters. For indicating, recording and integrating the flow of steam, feed water, compressed air and other fluids.

Coal Meter

Granular Material Meters For accurately measuring the flow of coal or other granular materials in gravity chutes from overhead bunkers. The total quantity of granular material is shown on a large illuminated counter which may be easily read at a distance of 50 feet.

Control Systems Make possible the everyday operation of equipment for steam generation and utilization at test efficiencies. They are applied to the control of combustion, feed water, superheat, desuperheat and other factors.

Complete Information on any of the above Bailey products will be gladly furnished upon request.

C-14

BAILEY METER • COMPANY •

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BAILEY METER COMPANY LTD., MONTREAL

The Month's NEW INSTRUMENTS

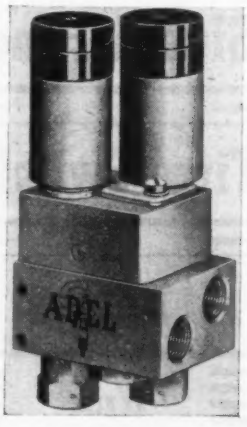
Multiple-contact Variable Resistor

New multiple control is operable either as a rheostat or as a "multiple potentiometer." Novel feature is that a number of contactors roll upon a single resistance coil.

Each of the contactors is in the form of a twisted bar and is insulated from each other contactor to engage successive convolutions of the coil to permit accurate control of the current or potential without influencing the current delivered by any of the other contactors. Photograph shows a unit having six contactors but it can readily be made with any desired number. New unit fits into and occupies the space heretofore required for a single unit of conventional design "with very little increase in weight." It is said that more compact applications incorporating variable resistors can readily be designed with these new multiple rheostats and voltage-dividing resistors to facilitate centralized positive control of electrical units and provide improved operating efficiency and accessibility with a substantial saving in weight and space requirements. —*American Pattern & Mfg. Co., 916 Fisher Bldg., Detroit, Mich.*

Aircraft Hydraulic Selector Valve

New solenoid-operated 4-way hydraulic selector valve is said to offer advantages of light weight, greatly accelerated action and



low current consumption. It measures 2⅝" × 2⅞" × 7 3/16"; weighs 4.1 lbs.; and is designed for aircraft installations located some distance from flight station (such as bomb bay doors, landing gear, wing flaps, etc.) where its use reduces length of hydraulic lines and effects weight savings. Current of 12 amps. at moment of impulse automatically drops at completion of stroke to holding pull of only 0.2 amp. at 24 volts d.c. Body is fabricated from dural bar stock. Valve has steel poppets with replaceable steel seats. Shaft furnished for manu operation. Electrical connections for eith 2-wire or 1-wire and ground circuits. Term nal posts are protected by plastic cap Unit withstands both continuous duty an rapid cycling, operates at pressures up 1500 lbs./in.². — *Adel Precision Produc Corp., Burbank, Calif.*

New Line of Rotameters

New "Series R-100" have several impo tant features claimed to be exclusiv These instruments are of the indicati

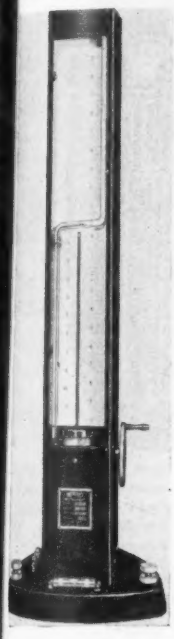
area meter type, in sizes fro ⅛" to 3", with both free an guided floats. Floats may be vi cosity-compensated or densit compensated. Metering tubes a of extra-heavy-wall Pyrex bor silicate glass formed on mandrel annealed, polariscope-inspecte and check-gaged by precision bo test. Features include: (1) Sprin stop floats, to prevent damage float by sudden surges of liqui (2) High-pressure stuffing boxe permitting use of corrosive liqui under high operating pressure (3) Single external adjustment stuffing boxes by wrench, inste of taking up successively a num ber of bolts or screws. (4) Whit backed metering tube for eas reading. (5) Interchangeab calibration scales for quick an inexpensive change from one ser ice to another. (6) Constant-ten sion guide rod, anchored in end of glass tube instead of in en fittings, can therefore be accu rately centered and its tensio will be unchanged by repeate stuffing box adjustment. (7) Fo test accuracy work, guide rod ca be supplied with spring loading feature secure ideal precision of alignment. Thi new "Cochrane-Rotameter (Inc.)" line Rotameters covers: Stet free float an liquid float types (260 mm. 10 in. scal length). Extra length guided float typ (625 mm. 25 in. scale length), Dashpo Type for pulsating flows, panel mountin type. portable type, Rotameters for opaqu fluids, Rotameters for vapors containin condensibles, Rotameters with remote ind cators, recorders, integrators, automati controllers and automatic proportioners.— *Cochrane Corp., 17th St., at Allegheny Ave Philadelphia 32, Pa.*

Dielectric Test Set

New "Model 1031-C Dielectric Test Set provides a convenient d-c source for volt age breakdown tests up to 4000 volts. It half-wave rectifier circuit, utilizing a 2X tube, delivers up to 18 ma. and is provided with a resistive guard circuit so that mo mentary shorts on output do not damage in

ument. High-voltage output is delivered safety connectors to which 24" flexible les, heavily insulated and terminated in voltage test prods, may be readily nected. Ground terminal is provided h a heavy-duty clip. Charge and dis- rge of capacitive test specimens, as well breakdown of the insulation under test, indicated by a neon glow lamp. An out- indicator shows voltage being applied specimen and a primary "Variac" pro- es continuous control of output voltage. is said that an important feature of s instrument is that no extended warm- period is required—test voltage is avail- le practically as soon as instrument is ned on. Unit is self-contained in a well- ntilated steel cabinet 8" × 10" × 8" and provided with a flexible cord and attach- nt plug for connection to a 110-volt 60- le circuit. — *Technical Apparatus Co., 71 Tremont St., Boston 20, Mass.*

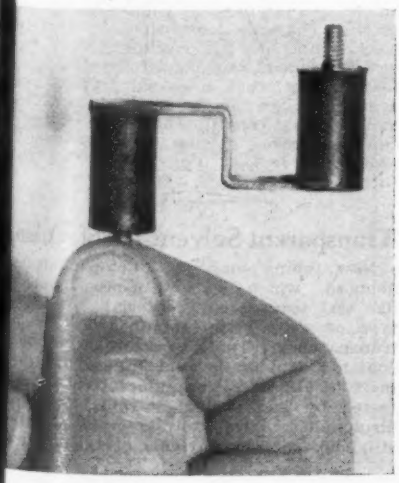
Precision Manometer



New "Meriam Micromanometer" has ments and is suit- able also for read- ing pressures and vacuums. A highly sensitive instru- ment, the Meriam Micromanometer permits readings to now on the mar- pressure. It is said to be "quite differ- ent from anything been developed for calibrating low- pressure instru- ± 0.001" water ket." In simplicity of operation it is said to surpass the hook gage. It is "not the least com- plicated or mysteri- ous" and can be handled successfull- ly by the average operator. — *The Meriam Instrument Co., 10958 Madison Ave., Cleveland 2, Ohio.*

Shock-absorbent Mounting for Instrument Panels, etc.

New type of resilient mounting utilizes ubber or other elastomers in the shape of linders interconnected by arms in S-fash- n. This arrangement is said to permit an tremely soft suspension under light load; nd to allow the resilient material freedom movement in all directions. It will han- le a variety of stresses including shear, ending, torsional or twisting. New mount- g also permits material to be stressed



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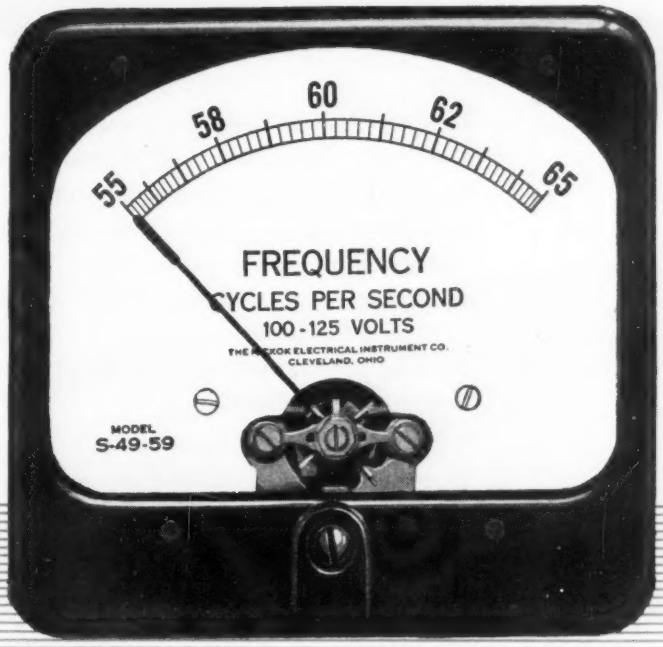
Self-Contained

Direct Indicating Type



Frequency Meters

HICKOK Frequency Meters are designed with electrodynamometer movements without use of external reactor. Made to operate at an accuracy equivalent to 3/10 of 1% at normal frequency. Used by the Armed Forces of the United Nations for maximum dependability. Model S-49 illustrated, is made for normal operating voltage of 90-140 or 180-280. 4", 5" and 6" sizes. Write today for your copy of new meter catalog ready soon.

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THE STANDARD OF QUALITY FOR A THIRD OF A CENTURY

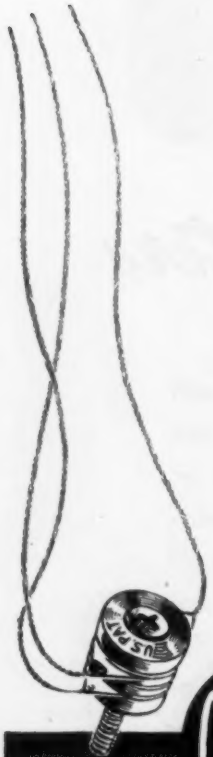
experience Counts!

Here at Conant Laboratories, we're old timers in a new business. Eleven years ago, we began the manufacture of Conant Instrument Rectifiers to fill a definite need. Today our production is more than 200 times as great as during our first year, and we've learned a lot. We've gone far toward making rectifier type instruments dependable.

By concentrating strictly on the manufacture of rectifiers for electrical measuring and indicating instruments, we have gained the experience so necessary to precision production.

Conant Instrument Rectifiers are not adaptations of power supply rectifiers, but were, from the beginning of our company, developed exclusively for meters.

Yes, indeed, we've gained a lot of "know-how" in our eleven years of research and production. If you have need of a rectifier-instrument application, you'll want to avail yourself of our practical experience.



CONANT *Instrument Rectifiers*

ELECTRICAL LABORATORIES

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85 E. Gay St., Columbus, Ohio
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1215 Harmon Pl., Minneapolis, Minn.
2017 Grand Ave., Kansas City, Mo.
7935 Eustis St., Dallas, Texas
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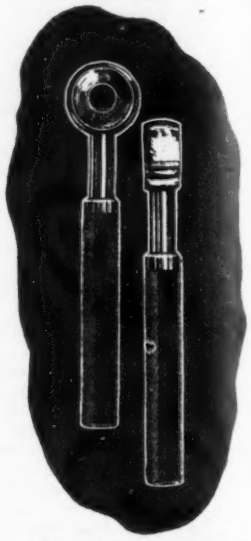
1526 Ivy St., Denver, Colo.
4214 Country Club Dr., Long Beach, Calif.
4205 N.E. 22nd Ave., Portland, Ore.
Caixa Postal 930, Sao Paulo, Brazil
50 Yarmouth Rd., Toronto, Canada

simultaneously under both shear and tension. Various arrangements of the rubber cylinders and arms to which they are attached will change the rate of deflection of the new mountings in any direction. Applications include housings for aircraft compasses and other instruments, flexible power transmission couplings, etc. Degree of movement permitted by the cylindrical resilient bodies is said to allow action in any direction to be controlled by the way in which the mounting or groups of them are installed.—*B. F. Goodrich Co., Akron, Ohio.*

Spherical Gage

New special gage has been developed to check ball fittings. Tool steel gage member is a true spherical segment securely attached to a knurled handle. It is said the



new gage will accurately gage ball socket or spherical concavity and instantly reveal any errors of machining. It is made in "Go" and "No Go" types.—*Vard Inc., 296 East Colorado Street, Pasadena 8, Calif.*

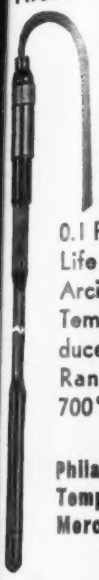
Insulation Tester

New "Model C-2 Megohmer" (insulation tester) is said to be a radically new development inasmuch as a new spillproof lightweight storage battery is used as the power supply for the 500-volt d-c. test potential used in making insulation resistance measurements. System employed is that of stepping up this low voltage battery to the steady test potential of 500 volts d.c. by means of a special vibrator transformer circuit built into the instrument. Battery can be readily replenished by recharging. For this purpose, a special charging circuit is also built into the instrument which makes it possible to charge the battery either from a.c. or d.c. at any time. Instrument is direct-reading in megohms and ohms, has knife-edge pointer and mirror scale, is ruggedly constructed, compact, and easy to operate. Announcement states that new instrument is exceptionally inexpensive to maintain; that a special feature is exceptionally low current drain from battery and also that condition of charge of battery can be checked at any time.—*Herman H. Sticht Co., Inc., 27 Park Place, New York City.*

Transparent Solvent-proof Tubing

New tubing made of "Compar" is announced, which is solvent-proof, rubber-like and transparent. Material is a special type of vinyl resin. In laboratory use its transparency permits constant inspection of contents. Tubing is said to be completely inert to almost all organic solvents; unaffected by such active solvents as carbon disulphide, carbon tetrachloride, trichlorethylene, perchlorethylene, acetylene tetra-

Philadelphia Merc-to-Merc Thermo-Regulators Feature



Mercury to Mercury Contacts : Increased Contact Capacity : Sensitivity within 0.1 F. Exceptionally Long Life and Stability : No Arcing : No Oxidation : Temperature Lag Reduced : Temperature Ranges adjustable to 700°F.

●

Philadelphia Merc-to-Merc Temperature Controls and Mercury Plunger Relays

●

The Philadelphia Thermometer Co.
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Amthor

STATIONARY TACHOMETERS

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Indicating R.P.M., F.P.M., etc.
Belt, Sprocket, or Flexible shaft drives

Models available for practically every requirement.

Immediate and intelligent attention will be given to your inquiries on all industrial speed measurement problems. Drop us a line today.

Amthor Testing Instrument Co., Inc.
47a Van Sinderen Ave. Brooklyn, N. Y.

Shallcross WIRE-WOUND SURGE RESISTORS

TYPE 290
RANGE: 1000 to 3,000,000 ohms

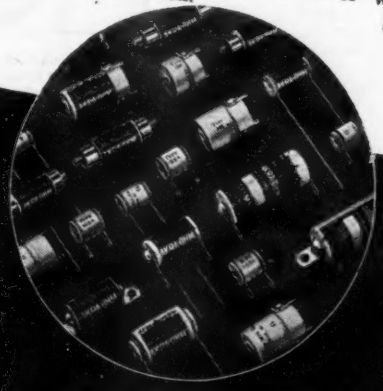
Developed for the X-Ray and other high-voltage applications, Shallcross Surge Resistors match up-to-the-minute requirements for high-resistance wire-wound resistors capable of handling high voltages, while dissipating normally 200 watts. A typical application is their use in the constant potential DC output of a high voltage Kenetron rectifying system to stabilize the performance of the apparatus to which this high potential is being supplied.

Descriptive data on request

Shallcross ACCURATE, HEAVY-DUTY Wire-Wound Resistors

These sturdy units meet popular favor with instrument manufacturers and others who require small, accurately calibrated resistors capable of handling high currents. They are also widely used as voltmeter multipliers in low-resistance AC or DC instruments. Normally rated at 10 watts, these Shallcross Type RM AKRA-OHMS are supplied to a standard accuracy of 2% and can, of course, be calibrated to closer tolerances where desired. They are water-proof, humidity-tested, and capable of withstanding salt water immersion.

Write for folder



EXACTING RESISTORS FOR EXACTING JOBS

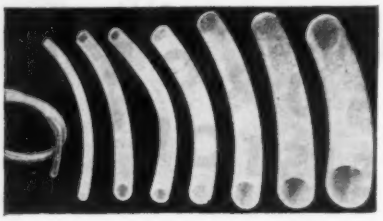
As long-time specialists in the production of close-tolerance resistors, Shallcross offers a complete line covering practically every need. Write for AKRA-OHM Catalog.

SHALLCROSS MFG. CO.

DEPT. IS-64, COLLINGDALE, PA.

ENGINEERING • DESIGNING • MANUFACTURING

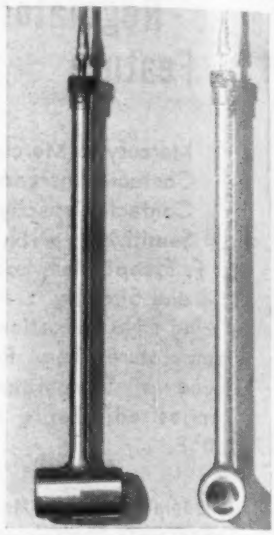
chloride, benzol and toluol or by oils and fuels such as high-octane gasolines with highest aromatic content. Therefore it is said to be useful for low-pressure room-



temperature handling of these hard-to-handle materials. It is said to have lowest permeability to gases of all natural and synthetic elastomers and to be unaffected by such gases as freon, methyl chloride, methyl bromide, phosgene, mustard, propane, butane and water gas. When used on Bunsen burners or other laboratory appliances tubing does not absorb protective odors with which illuminating gases are usually loaded and, therefore, prevents laboratory atmosphere from being contaminated by them. In aircraft, its transparency permits use as temporary mercury manometers and taking moving picture records during test flights for checking flight instruments. While this new transparent laboratory tubing is said to be extremely tough and strong, it is not generally recommended for industrial applications which now employ fabric-reinforced hose constructions containing tubes or cores of other "Compar" formulations: manufacturer can supply these others for aircraft instrument and hydraulic lines, etc. —*Resistoflex Corporation, Belleville, N. J.*

Probe Type Thermocouple Hea for Hot Gases

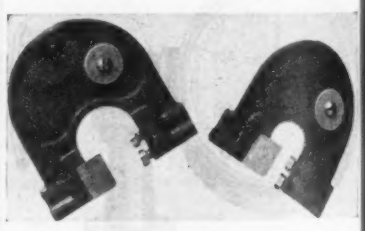
New "Revere Shielded Thermocoup Probe" has been developed to explore th temperature distribution where hot gases a employed. It is constructed entirely of stai



less steel with a replaceable Chrome Alumel thermocouple unit. The therm couple bayonets in the tubular shank a the junction extends to the center of t head shield. The head is fabricated fro four shields with Fuller's earth packed b tween alternate shields. The use of Fuller earth, a collodial anhydrous aluminu silicate, provides effectively eight shields minimize radiation heat losses. Units a provided with a bushing support to perm axial adjustment and are available wi various size heads to fit either general specific installations. — *The Revere Co pany, Dept. I, Box 804, Wallingford, Co*

Adjustable Snap Gages

Four new "midget type" models of a justable limit gages are announced. The are manufactured in accordance with Ame ican Gage Design Standards; are design



for checking and inspecting extremely sm and delicate parts; can be set to hand work from 0.000 to 0.760".—*George Sche Co., 128 Lafayette St., New York 13, N.*

High-contrast Agent for X-ray Films

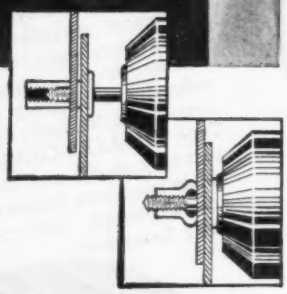
New "High Contrast Powder" intensifi all types of x-ray film, is supplied in u quantities each of which is for one gall of high-contract solution. Through its us radium exposure times can be cut in hal hidden details revealed; diffraction lin clearly defined; and underexposed film salvaged.—*St. John X-ray Service, In Long Island City 1, N. Y.*

Wire-wound Surge Resistors

New "Type 290 Wire-Wound Surge R sistors," developed for x-ray and othe high-voltage applications, meet modern r quirements for high-resistance units capab of handling high voltage, while dissipatin normally 200 watts. Typical application in the constant-potential d-c. output of

Ingenious New
Technical Methods
Presented in the hope that they will prove interesting and useful to you.

New Air Tool Drives "blind" Rivets Accurately... Automatically



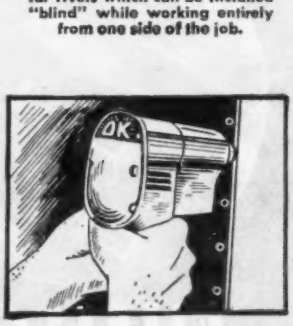
Rivnuts (mfd. by B. F. Goodrich Co.) are internally-threaded tubular rivets which can be installed "blind" while working entirely from one side of the job.

Installing "blind" RIVNUTS quickly with precise, positive upset while working entirely from one side is now possible with the recently developed Auto RIV-Driver. Completely automatic, the tool runs a threaded mandrel into a Rivnut, upsets it, backs the mandrel out and stops the tool. Operators simply press a throttle; make no manual adjustments for any operation. Rivnuts are installed 6 to 8 times faster than formerly; rejects are almost completely eliminated.

The tool can be adjusted to upset at any depth required. Once set, adjustment is tamper-proof—every Rivnut is driven accurately and uniformly. An indicator on the tool handle lights when the upset is correct; does not light if Rivnut is improperly headed.

Powered by compressed air, the Auto RIV-Driver weighs just 4¼ pounds; is 9½ inches long; balanced for efficient handling by women operators.

You all know that our fighting men need the finest quality materials that we here at home can produce. That goes for Wrigley's Spearmint, Doublemint and "Juicy Fruit" chewing gum, too. Our stock pile of raw materials that goes into the making of Quality chewing gum is getting lower and lower. Until we can again build up our raw material inventory, we are sending all of our limited output of Quality chewing gum to our fighting men and women overseas, only.



Automatic action, positive depth control and visual indicator assure correct and uniform installation of rivnuts with new Auto RIV-Driver

You can get complete information from the Independent Pneumatic Tool Co., 600 W. Jackson Blvd., Chicago 6, Ill.

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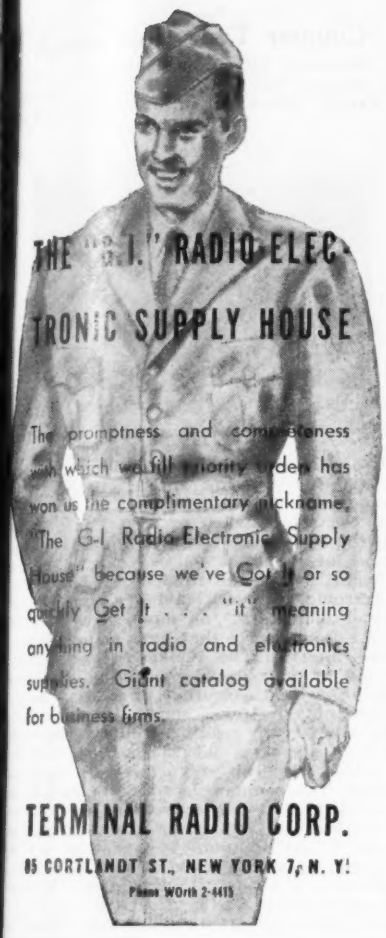
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The promptness and completeness with which we fill priority orders has won us the complimentary nickname, "The G-I Radio-Electronic Supply House" because we've Got It or so quickly Get It . . . "it" meaning anything in radio and electronics supplies. Giant catalog available for business firms.
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WHEATSTONE BRIDGE

Rubicon Wheatstone and Kelvin Bridges are available in a number of types to suit various applications. All are made in accordance with the highest traditions of the instrument maker's art and are fully guaranteed.

Described in Bulletin 100 which also lists National Bureau of Standards and other standards of resistance.

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Electrical Instrument Makers
Ridge Ave. at 35th St. Philadelphia 32, Pa.

Palmer will be ready for YOU

There will be no "reconversion waiting period" for Palmer Thermometers.

While we are kept busy now producing thermometers, for which there is yet a critical need, we are not unmindful of your Post War needs.

Palmer Thermometers that have withstood the stress of war duty will be much improved, retaining their fundamental tough quality and their extreme accuracy and sensitiveness for which they have been famous.

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Mfrs. of Industrial Recording and Laboratory Thermometers
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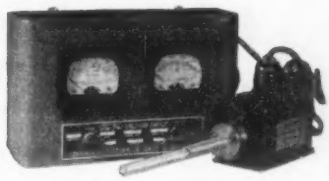

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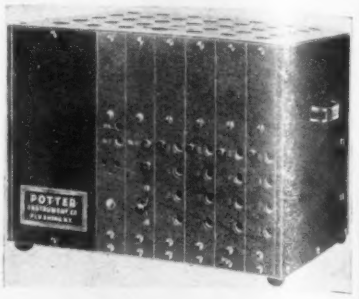
high-voltage Kenetron rectifying system to stabilize performance of apparatus to which this high potential is being applied, the resistors operating either as bleeders or as voltmeter multipliers. New Surge Resistors are wound on non-hygroscopic forms with insulated Nichrome wire, single layer space-wound. Wire is protected with a special finish which assures operation at 450°F. Resistance values from 1,000 to 3,000,000 ohms are available.—*Shallcross Mfg. Co., Jackson & Pusey Aves., Collingdale, Penna.*

Miniature Inductor Coils for H-f. Tuned R-f. Circuits

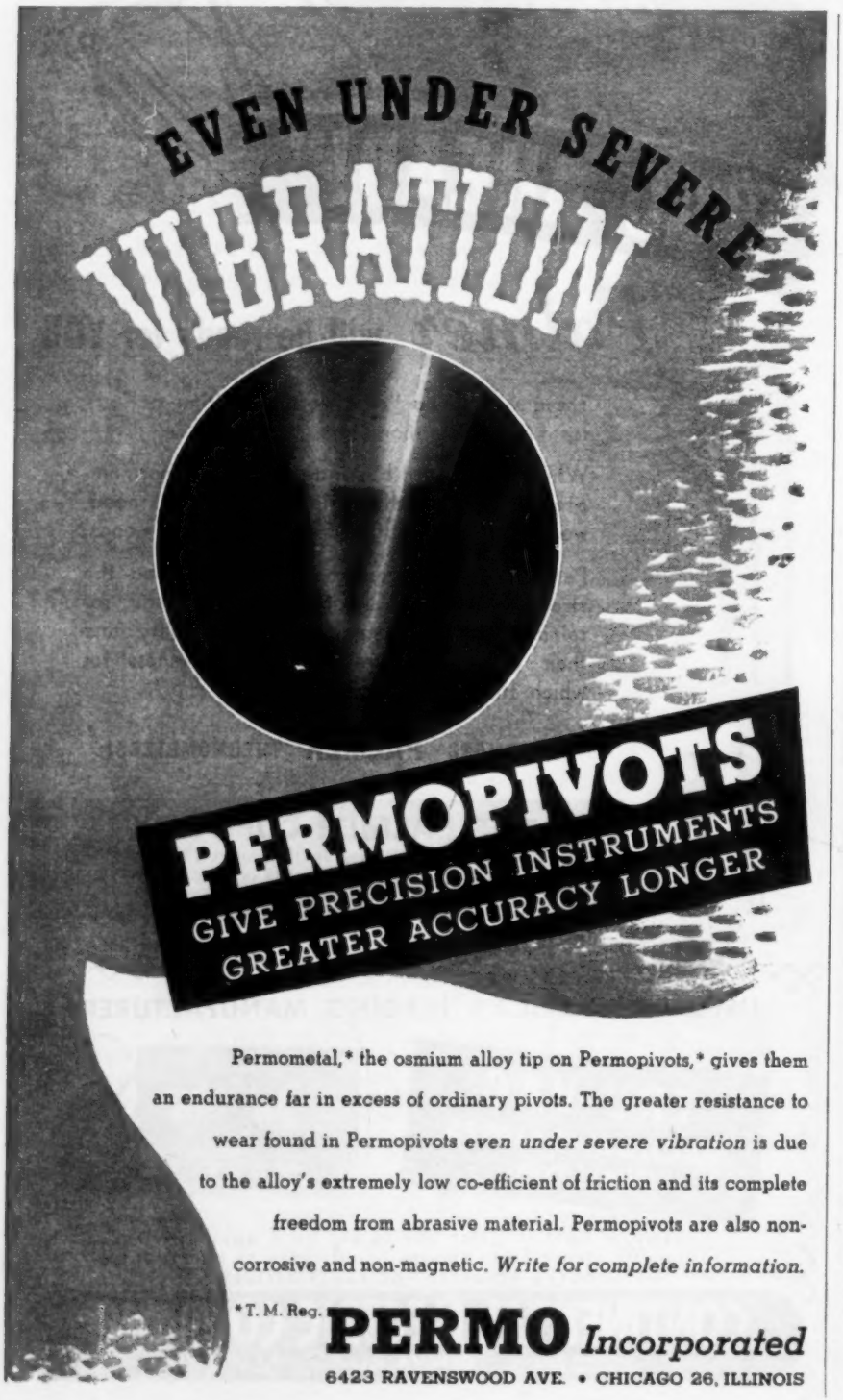
New "Miniature Air Inductor Coils" offer a wide range of engineering possibilities in high-frequency radio and other electronic applications. They are regularly supplied in diameters from ⅛" to 1¼". "Air wound" construction assures maximum rigidity and accuracy, with lightest possible weight. *Q* characteristic is said to be amazingly high by reason of almost total absence of insulating material in the electric field. Any type of mounting can be supplied, and the little coils can be equipped with fixed or variable, internal or external coupling links, and many other features to match practically any specification. There are five standard diameters and each diameter is available in any winding pitch from 44 to 4 turns per inch, or less if required. Wire sizes range from No. 14 to No. 28 and almost any desired type of wire can be supplied. New Miniature Coils are readily adaptable to every requirement from complicated band-switching assemblies to "tailor-made" coupling link units, or sturdy, easy-to-mount coils for any tuned r-f circuit. Design adaptations are said to be limitless.—*Barker and Williamson, 235 Fairfield Ave., Upper Darby, Pa.*

Counter Type Chronograph

"Accuracy hitherto impossible to attain" is claimed for new "Counter Chronograph Interval Timer." Instrument embodies a



100-kc. crystal-controlled oscillator to generate the counting rate; and electronic counters to indicate interval. In operation an electronic switch or "gate" is first actuated by a pulse from the initiation of the time interval. The pulse generated by the termination of the time interval turns the electronic gate off, leaving a count on the panel indicators: the number of cycles of the 100-kc. source that have elapsed in that time interval. The 100-kc. frequency is divided by four decades down to an output of 0.1 second. Accuracy is said to be ±1 cycle of the 10-kc. source, or ten microseconds for any reading. Full-capacity reading of panel is 0.09999 second, but the counter can "run over" this reading if desired. The counter decades are said to be unique in that only four tubes are used for counting and indicating a scale of ten in each "digit" column. The answers are indicated for each decade on four neon lamps designated 1-2-4-8. Combinations of these lamps indicate 0 to 9. (Thus $4 + 2 + 1 = 7$.) Instrument operates from a line voltage of 100-125 volt 60-cycle a.c. Tube complement is 27 tubes. Plug-in construction of the units is used throughout. Dimensions 15" × 10" × 10"; weight approx. 30 lbs.—*Potter Instrument Company, 136-56 Roosevelt Avenue, Flushing, N. Y.*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Anti-glare Treatment for Glass and Other Materials

New method of reducing light reflections from glass and other materials, consists of a surface treatment which reduces reflections on large areas of glass, plastics, varnished wood, oil paintings, glossy paper and photographs. Previous methods of removing reflected light, it is said, were limited to glass and were practical for relatively small pieces only. Ordinary glass transmits about 92% of light, the remaining 8% being lost through surface reflections. Much of this lost light is saved by the new surfacing technique which does not damage the original surface of the treated substance. Undersigned company announces also that it is prepared to treat small quantities of lenses, prisms and other optical elements up to 12" used in government orders. Concerns holding military contracts can secure supplies of the new coating and instructions on its applications.—*American Optical Co., Southbridge, Mass.*

Spark Plug Test Stand

Two new fully-equipped spark plug test and service stands on wheels for shop and field have been developed: Model P-90 for mica plugs, Model P-95 for ceramic plugs. Both stands contain a Wheatstone bridge circuit and pressure test bomb for testing, or, if specified, a motor and magneto combination may be substituted. To determine electrical condition, frequency and quality of spark under simulated engine conditions, a high-pressure test chamber is arranged. This operates with a CO_2 bottle, taking pressures up to 750 lbs. Appropriate tools are built into each stand for adjusting elec-

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Off on field work—into the air—wherever you go, the Hathaway S-12 is the compact, performance-perfected instrument for geophysical work, field testing, and aviation flight testing . . . as accurate as your laboratory Oscillograph, as easy to take with you as your hat!

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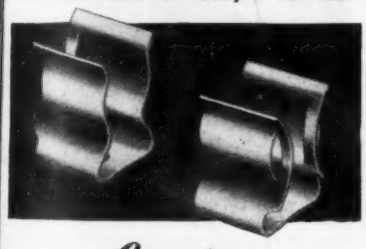

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Exclusive Littelfuse design effects contact *over largest possible area.* Results: Extra tight grip—maximum electrical conduction—less heat—loss of clip-temper prevented—spring qualities retained much longer.

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Readability to 1 RPM per division. Guaranteed accuracy well within ½ of 1%. Indicates RPM directly on the dial without any calculations over a fixed period of 6 seconds. Negligible torque. Two models with ranges 0-1000 RPM or 0-10,000 RPM, each suitable for double rated range.

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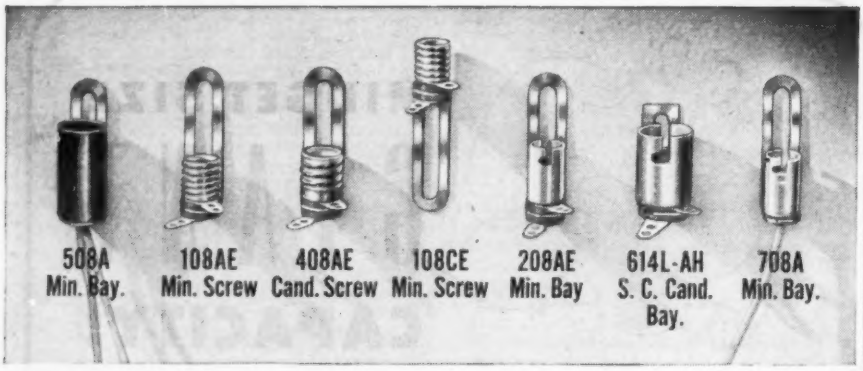

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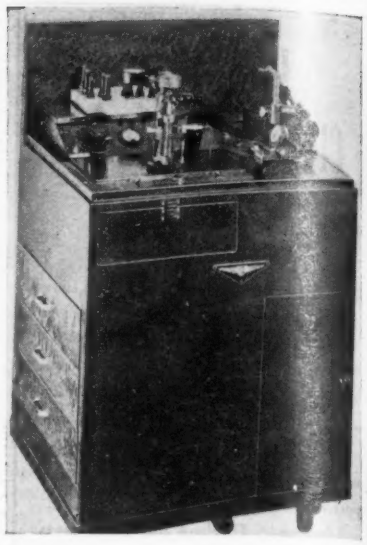
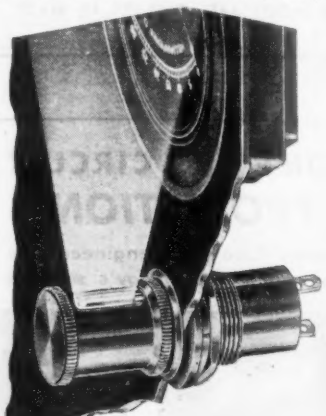


trodes. A storage compartment for 432 plugs, and a large tool and parts drawer are conveniently arranged. Heavy-duty rubber-tired ball-bearing wheels make stands easily movable, and any 110-volt a-c. line provides sufficient power.—*Mfg. Division, Air-Plane Mfg. & Supply Corp., 6853 Lankershim Blvd., North Hollywood, Calif.*

Panel Light Assembly

New panel light (light-shield) assembly is designed to improve lighting of instrument panels, etc. Main design feature is knurled head which is rotatable 360°, thus



casting the light at any desired angle. Lamp housing is made of Navy specification Bakelite sealed with Bakelite varnish, while head is made of brass and may be finished with any desired plating. Lamp socket accommodates miniature bayonet base lamp which is easily removable from front of panel. Unit is compact and rugged, requires ½" panel hole for mounting.—*Dial Light Co. of America, Inc., 900 Broadway, N. Y. 3, N. Y.*

Insulation Tester

New "Model 665 V.T. Volt Ohmeggor Insulation Tester" is said to be equivalent to 29 measuring instruments in one. It provides insulation testing at 500 volts up to 10,000 megohms with two other features—a "comprehensive electronic multitester not included in other similar types of insulation testers," and a capacitymeter measuring as low as 2.5 micromicrofarads and up to 2,000 microfarads. It includes VR 105-30 voltage regulator tube and its associated circuits, insuring freedom from line voltage fluctuation error; 13 a-c. and d-c. voltage scales, measuring from a fraction of a volt to 6,000 volts. Tester is direct reading, complete, ready to operate; with high-voltage test leads, r-f. lead; signal tracing probe. Vacuum-tube voltmeter on all ranges. In-

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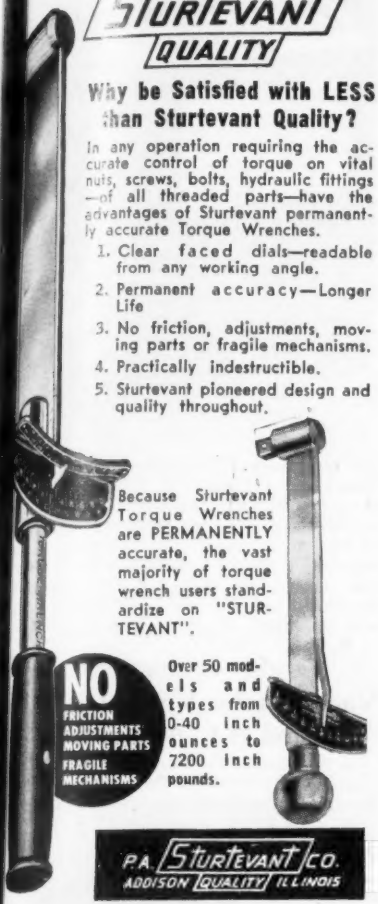

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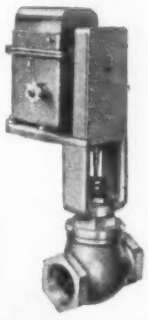
MICRO SYSTEM FOR PROCESS CONTROL

The temperature-sensitive Remote Bulb Microtherm contains an SPDT switch, operated by changes in temperature, controlling the direction of rotation of the valve motor. In the Valve motor unit a potential dividing rheostat, keyed to the driving shaft, changes the pull of a solenoid on the SPDT switch tongue so that the switch opens when the valve reaches the desired new position. Thus the Microtherm is able to position the Proportioning Valve so as to satisfy exactly any change in demand. "Hunting" is eliminated, no current or potential-sensitive relays are required, and maximum power is available at every point of the valve stroke. The "droop", or throttling range of the instrument is adjustable. For temperature control with "micrometer accuracy", use the Barber-Colman Micro System.



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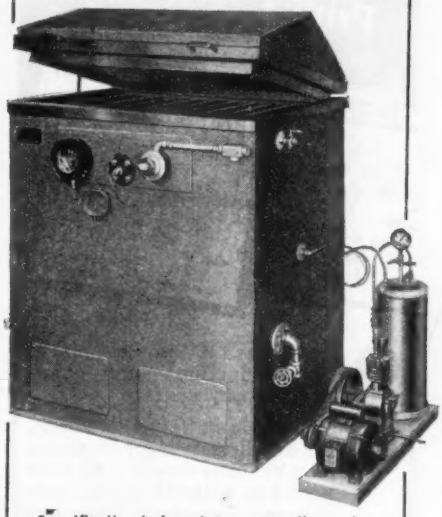

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Model 201 VIBROTEST

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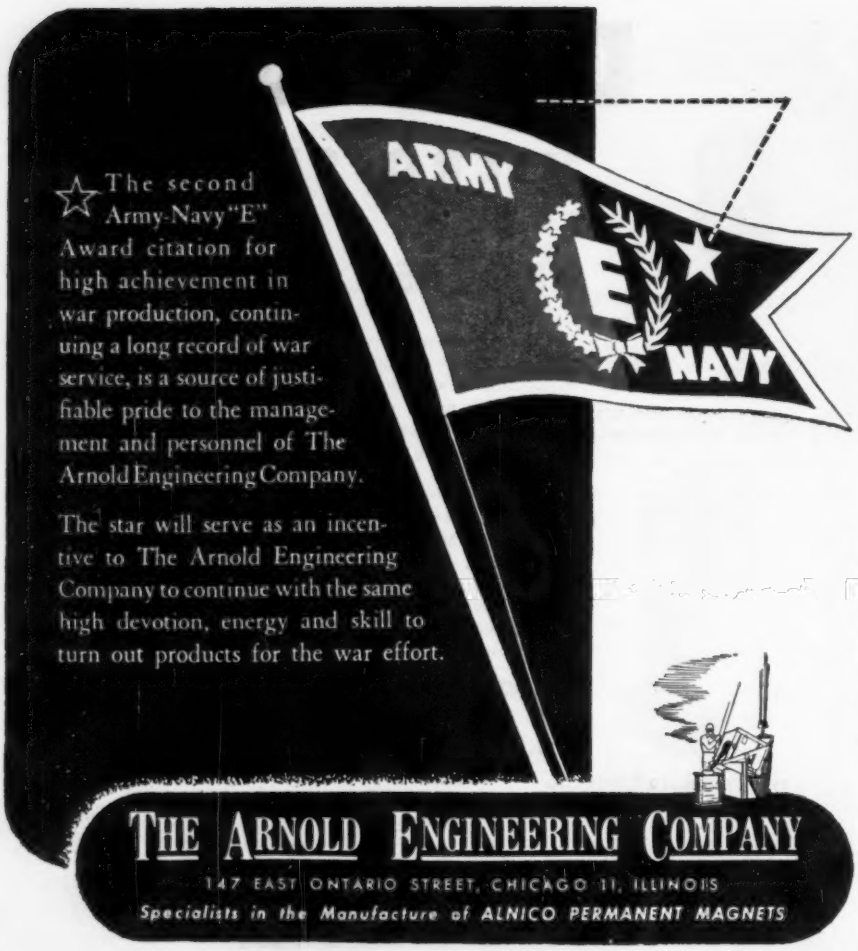

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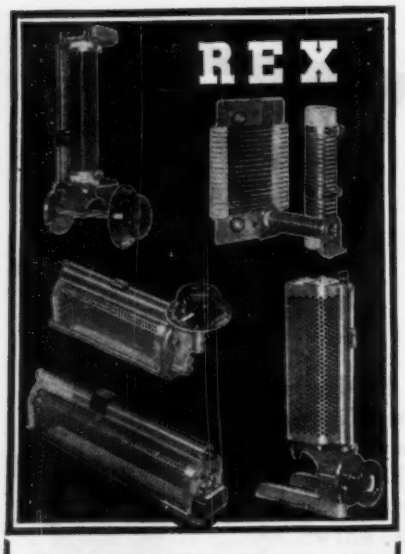

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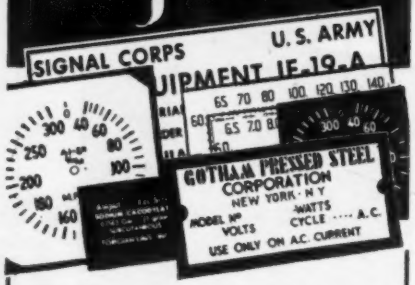

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put resistance 16 megohms maximum. V ohmmeter, 7 ranges to 1,000 megohms, n danger of shock. Linear-movement 8" D'Ar sonval microammeter with accuracy of 2% of full scale, maximum protection agains burnout, cannot be damaged by checking a live resistor or using too low a range fo making a measurement.—*Radio City Prod ucts Co., Inc., 127 West 26th St., New Yor 1, N. Y.*

Vacuum-tube Voltmeter for R-f and A-f. Applications

New "Model 200" and "Model 201" vac uum-tube voltmeters, for audio- and radio-frequency applications such as productio

and laboratory measurements by communications and electronic equipment manufacturers, are said to inclue these special features: high sensitivity, stabilized zero, and a built-in standard cell for calibration checks. A-c. voltage ranges: 0.5-5-50-200 full scale. Frequency range from 2 cps. to 150 Mc. New voltmeter is accurate to 2% of full scale on voltage, 2% on frequency to 150 Mc. Resonant frequency: 350 Mc. Another feature is described as "automatic zero adjustment on all ranges." Readings vary 1% with 10% line voltage fluctuation. Model 201 (illustrated) has built-in probe, input capacity 10 mmf. Model 200, same as 201, but with separate probe, input capacity, ½ mmf.—*Televiso Products, Inc., 6533 No. Olmsted, Chicago 31, Ill.*

Combination Megohmeter and Capacitor Leakage Tester

New "Model L-2 Megohm Meter," essentially a direct-reading ohmmeter but incorporating a vacuum-tube voltmeter in order to cover relatively high resistance values.

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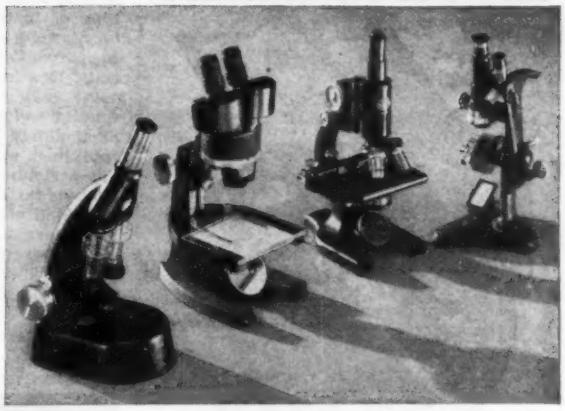

Wartime achievements in research and process control owe much to the optical instruments which extend vision and provide a means of measuring optical characteristics.

The Spencer Colorimeter is designed for convenience. The built-in illuminator and inclined eyepiece permit a comfortable position for the operator. Direct reading drums and separable cups speed up use.

The Stereoscopic Microscope extends human vision, retaining the natural position and movement in manipulating for careful inspection of detailed materials.

The Standard Laboratory Microscope with mechanical stage is easily equipped to provide the various types of illumination and magnification needed in industrial research and process control.

Four different Spencer Refractometers are now being produced for index and dispersion measurements of solids and liquids.

Although the demand on Spencer's facilities for the production of optical equipment for warships, planes, tanks and guns has been great, we have been able to supply many vital war industries with urgently needed, indispensable scientific instruments.

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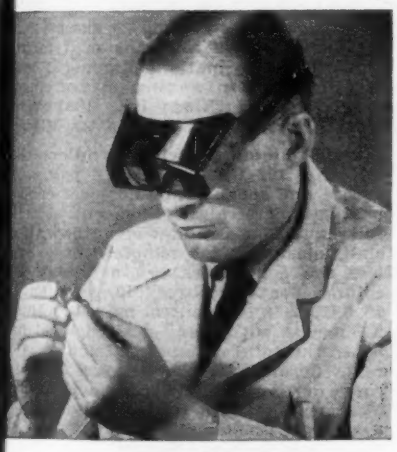

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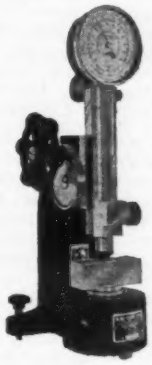

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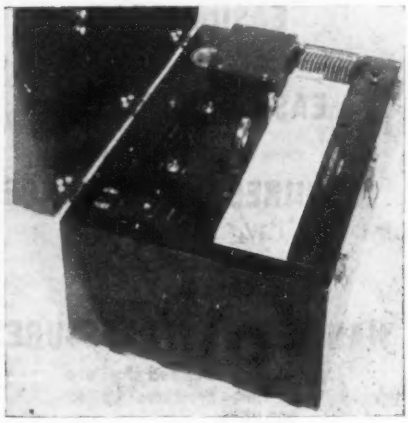

GARCEAU CHRONOGRAPH

Eleven Recording Channels
One Timing Channel

Through an inertialess electrical recording system, this Garceau Chronograph provides means of measuring without error the length of time an electric current flows. Tape can be withdrawn manually, to allow inspection of recent records, with provision for independently actuated electrical re-wind of used tape.

Tape speed is 20 centimeters per second. Timing channel prints a row of dots spaced at 1/60 second intervals.

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RUGGED—*yet*
SENSITIVE *and*
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Manufacturers' New Literature

In this department we report ALL pieces of new literature pertaining to Instrumentatio received from the manufacturers. To assist in the War Effort we urge readers to request ONL those bulletins which will be of value to them. Use the coupon on the facing page.

L-101 **Battery Connectors.** Catalog, 8¼" × 10½", 24 pages. Plugs and receptacles for aircraft battery, engine and general industrial applications requiring circuit connecting and disconnecting. Dimensional drawings and photographs illustrate all units. Condensed data sheets provide necessary information such as total contacts, shell material, weight, etc. Several pages are devoted to illustrations of specific applications and other facts of general interest. Cannon Electrical Development Co., 3209 Humbolt St., Los Angeles 31, Calif.

L-102 **Mechanical Water Regulation for Boilers.** Textbook, 6th Edition, 6" × 9", 32 pages. Fundamental principles of scientific feed water regulation by Edward P. Culver, Associate Professor of Mechanical Engineering, Princeton University. Contents amply illustrated by drawings, charts and photographs. Northern Equipment Co., 1945 Grove Drive, Erie, Pa.

L-103 **Duragauge.** Bulletin, 8½" × 11", 12 pages. Pressure gages, for industrial applications, having an accuracy of ½ of 1% of dial graduation over entire scale of 270° dial arc. Text includes information on construction and design of movement and system, Phenol Turret case, dials, etc., with numerous illustrations. Specifications listed in chart form for quick selection for specific applications. Price lists included. Manning, Maxwell, and Moore, Inc., Bridgeport 2, Conn.

L-104 **High-vacuum Equipment.** Catalog, 8⅝" × 11¼", 25 pages. Physical and operational data on glass-metal pumps, glass single-stage pumps, glass two-stage and three-stage fractionating pumps, and metal fractionating, booster, and diffusion pumps. Ultimate vacuum obtainable varies from 10^{-4} mm. to 5×10^{-8} mm. at 25°C. Similar technical data also included for Pirani gages, ionization gages, vacuum greases, and pump oils. Price lists included. Distillation Products, Inc., 755 Ridge Road West, Rochester, New York.

L-105 **Quality Control.** Handbook, 6" × 9", 64 pages. Gages and instruments having microinch accuracy for quality control of the U.S. Standard Inch. The tools for such accurate measurements, i.e. gage blocks, optical flats, gage instruments, vernier gages, etc. (all a sembled in a carrying case), are ful covered in text which explains their u and the many types of measurement made possible by various combination Measurements within ±0.000002" accu acy are possible. The greater portion the contents is devoted to gage data ta bles and glossary. This includes such in formation as care of gages, how t wring gages, how to read microinche gage block specifications, conversion ta bles, trigometric solutions of triangle and other information of general inte est in precision gaging measurement Continental Machines Inc., 1301 Wash ington Ave. South, Minneapolis, Minn.

L-106 **Liquid Level Controllers.** Bu letin No. 102-R, 8½" × 11", 8 pages. Ac curate and sensitive liquid level control lers having straight line control actio for regulation of inflow or outflow. Espe cially designed for remote control serv ice, the controllers are available wit column floats of three different length 7", 14", 30". The control may be adjuste to operate within any desired level limi up to the total column float length. Con tents describe the advantages and fea tures of the unit and explain the theor of operation. Numerous photographs an drawings illustrate the controllers an their application. Natural Gas Equip ment, Inc., Petroleum Bldg., Los Angeles Calif.

L-107 **General Radio Experimente** March Edition, 6" × 9¼", 8 pages. An nounces appointment of new officers, an briefly describes the background an qualifications of each. General Radi Company, 30 State Street, Cambridge 3 Mass.

L-108 **The C-D Capacitor.** Jan-Feb issue, 5⅝" × 7⅝", 16 pages. Features tw articles. The first, "Square-Wave Testing of Amplifiers," explains a method fo testing the frequency response of ampli fiers by means of a square-wave gener ator and oscilloscope, eliminating th usual time-consuming point-to-point method. The second article, "Features o Inverse Feedback Amplifiers," discusses the theoretical as well as the practica features of inverse feedback, and ex plains the advantages which result. Cor nell-Dubilier Electric Corp., Hamilto Blvd., South Plainfield, N. J.

L-109 Oil Type **"Capacitrons."** Bulletin 102, 8½" × 11", 1 page. Hermetically-sealed oil type capacitors—single-hole mounting—having working voltages from 600 to 1500 v.d.c., depending upon the particular type. Standard capacities from 0.5 to 4 mfd. listed and illustrated by dimensional drawings and photographs. Capacitrons, Inc., 318 West Schiller St., Chicago 10, Ill.

L-110 **The Ohmite News.** February issue, 8½" × 11", 2 pages. Features an article on the Edison Effect, an electrical phenomenon discovered by the famous scientist while performing experiments on the incandescent lamp. Ohmite Manufacturing Company, 4835-41 Flournoy St., Chicago, Ill.

L-111 **Thermocouple Data Book and Catalog.** Bulletin No. S2-4, 8½" × 12", 36 pages. A valuable compilation of data on thermocouples, thermocouple lead wire, thermocouple wire, and thermocouple accessories. Contents also include useful and essential data such as checking pyrometers, checking thermocouples, making thermocouples, selection of lead wire, plus many others. In addition to informative text, data are presented in numerous tables which are supplemented by drawings and photographs. Wheelco Instruments Co., Harrison and Peoria St., Chicago, Ill.

L-112 **Selenium Rectifiers.** Bulletin No. 524-44-R, 8½" × 11", 1 page. Illustrates eight different types of rectifiers specifically designed for instrument and relay applications. Selenium Corporation of America, 1800 West Pico Blvd., Los Angeles 6, Calif.

L-113 **Electrical and Electronic Testing Instruments.** Catalog 128, 8½" × 11", 20 pages. Volt-ohm-milliameters, electronic voltmeter-ohmmeter-capacity meter, vacuum-tube insulation tester, electronic voltmeters and limit bridges, tube and set testers, signal generators, etc., all described by complete specifications and photographs. Radio City Products Co., Inc., 127 West 26th St., New York 1, N. Y.

L-114 **Cenco News Chats.** March issue, No. 44, 8½" × 11", 18 pages. Features a brief biography of Madame Curie and her search for radium. Contents also include descriptions of apparatus such as the "Photelometer," glass-electrode pH indicator, etc. Central Scientific Co., 1700 Irving Park Road, Chicago, Ill.

L-115 **Plastics.** Bulletin, 6" × 9", 8 pages. Describes printed and laminated cellulose acetate products of a wide variety available in colors from clear transparent to deepest opaque. Several pages are devoted to data showing physical, thermal, electrical and chemical properties. Text includes a review of production facilities. The Hopp Press, Inc., 460 West 34th Street, New York 1, N. Y.

L-116 **Aircraft Electric Tachometers.** Catalog Section GET-1215, 8" × 10½", 14 pages. Magnetic-drag type electrical tachometers designed for aircraft applications. Four-color catalog drawings, wiring diagrams, and photographs illustrate text which explains the theory of operations of these units. Cutaway drawings are available as wall charts for lecturing purposes. General Electric Company, Schenectady, N. Y.

L-117 **Electrical Instruments.** Catalog No. 16, 8½" × 11", 32 pages. Specifications and price lists for switchboard and portable electrical indicating instruments. A variety of ranges are listed for both a-c. and d-c. instruments having accuracies from 1% for switchboard instruments to ½ of 1% for portables. Dimensions and ratings of shunts and series resistors are also included. Data illustrated by photographs and outline drawings of accessories. Norton Electrical Instrument Co., Manchester, Conn.

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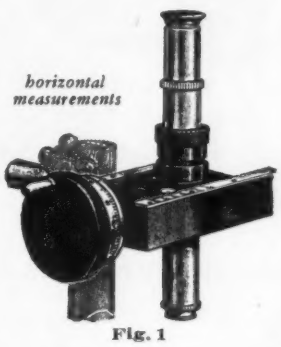

Fig. 1

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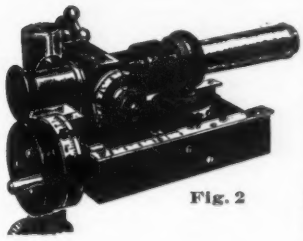

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Fig. 2

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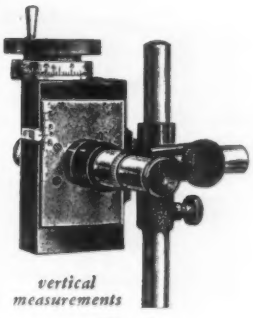

vertical measurements

Fig. 3

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